2017 DOKTORSKA DISERTACIJA MICHAEL DAVID BURNARD

UNIVERSITY OF PRIMORSKA
FACULTY OF MANAGEMENT

DOCTORAL DISSERTATION

MICHAEL DAVID BURNARD

KOPER, 2017

UNIVERSITY OF PRIMORSKA
FACULTY OF MANAGEMENT

Doctoral dissertation / doktorska disertacija

WOOD AND HUMAN STRESS IN THE BUILT INDOOR ENVIRONMENT / LES IN STRES V GRAJENEM NOTRANJEM OKOLJU

Michael David Burnard

Koper, 2017

Mentor: Assoc. Prof. Andreja Kutnar, PhD

POVZETEK

Naša raziskava stresa ljudi v grajenem okolju je zajemala pregled literature, anketo, ki je preverjala percepcije uporabnikov glede naravnosti gradbenih materialov, in eksperiment, ki je preverjal vplive uporabe lesa v pisarniških okoljih na stres ljudi. Pregled literature je pokazal potencial, ki ga imajo naravni materiali za spodbujanje zdravja pri ljudeh ob uporabi v notranjih prostorih. Anketa je razkrila, da uporabniki les zaznavajo kot naraven material. Študija stresa v pisarniških okoljih je pokazala izboljšanje stresnega odziva v pisarni s hrastovim pohištvom v primerjavi s pisarno, v kateri je bilo belo pohištvo.

Ključne besede: kortizol, gradbeni materiali, gradnja, dizajn, naravni materiali, regenerativni dizajn, restorativni dizajn, blagostanje ljudi

ABSTRACT

This study of human stress in the built environment included a literature review, a survey assessing user perceptions of building material naturalness, and an experiment to determine the human stress impacts of wood use in office-like environments. The literature review indicated the potential for natural materials to be used indoors to create healthy impacts for building occupants. The survey revealed wood was perceived as a natural material. The human stress study revealed improved stress responses in an office with oak furniture compared to an office with white furniture.

Keywords: cortisol, building materials, construction, design, natural materials, regenerative design, restorative design, human well-being

UDK:

ACKNOWLEDGEMENTS

I would like to extend my gratitude to the University of Primorska for its support of this project and the funding programs that provided support for this study. I acknowledge COST Actions FP1303 and FP1407. I further acknowledge the support of WoodWisdom-Net+ and the Slovenian Ministry of Education, Science, and Sport of the Republic of Slovenia for their support of the Cascading Recovered Wood project; the European Commission for funding the InnoRenew CoE project (Grant Agreement #739574) under the Horizon2020 Widespread-Teaming program, and the Slovenian infrastructure program IP-0035.

I would like to personally thank my friends Eric, Angela, Andreja, Matt, Amy, Marko, Mirna, Klavdija, Aaron, Christina, Saša, Črt, my family, and the countless others who supported me in my move to my new home in Koper, and who provided encouragement and acted as sounding boards while planning and conducting my research.

Special thanks are extended to my friend and mentor Andreja Kutnar for trusting me throughout the project and for providing invaluable support as I made my new home and career in Slovenia. I look forward to little more than continuing the work we have begun with our colleagues throughout Europe and across the globe.

TABLE OF CONTENTS

KAZALO

Table of Figures

Table of Tables

List of abbreviations

A-NS-SCR	Amplitude of Non-Specific Skin Responses
A:Control	Experimental condition in the stress experiment indicating the environment room A, with control (white) furniture
A:Oak	Experimental condition in the stress experiment indicating the environment in room A, with oak furniture
ANS	Autonomic Nervous System
ART	Attention Restoration Theory
B:Control	Experimental condition in the stress experiment indicating the environment room B, with control (white) furniture
B:Walnut	Experimental condition in the stress experiment indicating the environment in room B, with walnut furniture
CI	Confidence Interval
ELISA	Enzyme Linked Immunabsorbant Assay
F-NS-SCR	Frequency of Non-Specific Skin Responses
FAO	United Nations Food and Agriculture Organization
HFE	Human Factors and Ergonomics (or, Human Factors/Ergonomics)
HPA	Hypothalamus-pituitary-axis
HRP	Horseradish peroxidase
HW	Heartwood
IEC	International Electrotechnical Commission
ISO	International Organisation for Standardisation
KMERS	Komisija Republike Slovenije za medicinsko etiko
MDF	Medium-density Fibreboard
MVOC	Microbial Volatile Organic Compounds
OSB	Oriented Strand Board
PASAT	Paced Auditory Serial Addition Task
RED	Restorative Environmental Design
REED	Restorative Environmental and Ergonomic Design
rpm	Revolutions per minute
SBS	Sick Building Syndrome
TMB	tretramethylbenzidine
USGBC	United States Green Building Council
VOC	Volatile Organic Compound
WHO	World Health Organisation
WHO-5	World Health Organisation five question well-being assessment scale
WPC	Wood Plastic Composite
XML	eXtensible Markup Language.

1 INTRODUCTION

Most humans now spend most of their time indoors making the built indoor environment critical to maintaining and enhancing human wellbeing (Ulrich 1991; S. Kaplan 1995; USGBC 2011). Humans are affected by many aspects of their surrounding environment. Building design choices including material selection, ventilation, lighting, amongst others, and are therefore important to occupant health (Ulrich 1991). Decisions surrounding these aspects of a building should be made to create positive impacts for building users, not only to mitigate harm.

One strategy to enhance occupant health in the built environment is to attempt to bring the natural environment indoors. Nature and elements of it have been shown to provide positive psychophysiological impacts on individuals (R. Kaplan and Kaplan 1989; S. Kaplan 1995; Hartig et al. 1997; Herzog et al. 1997; Hartig 2004). Although there are design mechanisms and strategies to bring nature indoors such as biophilic design, people most often remain segregated from nature and its benefits while indoors (Kellert 2008). Biophilic design rests on E.O. Wilson's biophilia hypothesis, which posits an innate human connection to life and life-like processes: growing and dying plants, running water, variations in light, and other elements of nature (Wilson 1984; Kellert and Wilson 1993; Kellert 2008). By integrating natural elements in building design, occupants are expected to gain health benefits from the components and design of their built environment typically associated with nature.

The means of bringing nature into buildings include many methods such as providing views of nature, installing indoor plants or water features, varying light levels and temperatures, introducing variations in space, and using natural materials. Wood is a particularly interesting material for this purpose because it is widely available on the market, presents ecological advantages, used in many applications worldwide, and is widely recognised as a natural material (Burnard et al. 2017). Wood is a sustainable building material manufactured by nature with solar energy, which stores carbon (Salazar and Meil 2009; Sinha, Gupta, and Kutnar 2013). After conversion to building products (e.g., lumber, wood-based panels) wood has only a minute amount of embodied energy compared to other building materials and increases the pool of stored carbon in the built environment creating a positive impact on climate change (Sinha et al. 2013). Importantly, research has found using wood for interior treatments in buildings to have positive impacts on occupants, especially related to indicators of human stress (Tsunetsugu, Miyazaki, and Sato 2002; Sakuragawa et al. 2005; Rice et al. 2006; Tsunetsugu, Miyazaki, and Sato 2007; Fell 2010; Nyrud, Bringslimark, and Bysheim 2013).

Despite recent evidence of the health benefits of using wood in the built environment, and the theoretical framework biophilia provides, little is known about the underlying physiological, neurological, or psychological mechanisms that occur to cause them. Similarly, there are no evidence-based guidelines available to help designers achieve targeted health outcomes for building occupants based on using biophilic design or similar efforts to bring nature indoors.

1.1 Problem definition

Human stress can be considered in two broad categories: acute stress, which is the human "fight or flight" response; and chronic stress, the day-to-day stress load that has a cumulative effect (McEwen 1998). Although the extent of the reaction to stress (acute or chronic) varies in individuals based on their perception of the stressor, genetics, personal behaviour (e.g., smoking, diet, drinking, exercise, etc.), the physiologic responses to stress are known to have lasting effects on human health (McEwen 1998, 2008). These responses include increased heart rate, heart rate variability, blood pressure, release of glucocorticoids such as cortisol. The long term effects of these responses may lead to changes to the brain and its functions, inhibit immune responses, and may be related to depression, anxiety disorders, and lead to conditions such Cushing's disease (McEwen 1998, 2008).

Individuals may take action to address chronic stress by increasing sleep quality and quantity, maintaining a healthy diet, increasing physical activity, avoiding smoking, maintaining good social support, and utilising professional therapeutic support (Bernadet 1995; Rovio et al. 2005; McEwen 2008). Many structural societal practices or changes can impact the long-term effect of stress as well. Policies limiting the structural concerns that lead to stress such as wage sufficiency, access to healthy food, education, health care, and shelter can reduce the causes of stress (McEwen 2008). Beyond policy decisions, businesses may implement worksite interventions that encourage healthy lifestyles for their employees and lead to reduced stress and subsequently reduce insurance costs and increase workforce loyalty (Pelletier 2001; Whitmer et al. 2003).

Another potential worksite intervention to limit the effect of chronic stress is improvement to worksite and work conditions directly by changes to building design. Similarly, these interventions may provide the same benefits in houses, schools, and other buildings. Constructing buildings to limit negative health impacts is already regulated, though most regulations are limited to volatile organic compounds (VOC) emissions and toxicity (Bulian and Fragassa 2016; Burnard 2017). Interventions to building design decisions that may reduce stress or improve stress recovery have received limited research attention and those interventions already in the workplace are largely untested from a scientific perspective.

With a clear need to limit the negative effects of stress humans must contend with on a day-to-day basis, and the critical impact of building design on occupant health, improvements must be made to how buildings are designed and built that provide positive health impacts for occupants. Although bringing nature into the built environment may provide health benefits, it is not clear how any specific means of bringing nature indoors deliver those benefits. Under the tenets of biophilic design, there is a heavy reliance on including nature into the built environment to promote human well-being, however, there is little research defining how nature and naturalness are perceived indoors by building occupants. Therefore, it is important to understand how aspects of the built environment are perceived by building users and common construction and furniture materials are key components that must be understood.

Evidence is lacking to explain the types and effects of various design decisions that may improve occupant health, especially related to human stress. It also remains unclear how user perceptions of the naturalness of their indoor environment is involved in the stress mitigating effects that have been found in indoor environments with natural materials (e.g., wood furniture in offices as in Fell 2010).

This lack of evidence is problematic for designers' ready to implement evidence based solutions to provide occupant health benefits, and most importantly for building occupants who could receive significant health benefits with improved building design. Health benefits for occupants can directly impact company performance as well, for example by reducing sick leave and unplanned time away from work, or potentially by increasing employee productivity while at work.

The problems addressed in this research are two-fold:

- User perceptions of building material naturalness are not well understood and will likely have a significant impact the efficacy of health interventions based on including nature into the built environment, for example through biophilic design.
- The stress mitigation and restoration effects of using wooden furniture in offices shows potential to increase occupant well-being, but further investigation is required to understand the effect, and how to apply it in building design. Additionally, the specific attributes of wood that may contribute to stress mitigation and restoration effects are unknown.

Therefore, this research investigated user perceptions of building material naturalness to understand how material selection in building design may influence building occupant perceptions of their indoor environment and investigated the stress mitigation and restoration effects of using wooden furniture in office-like environments using robust, objective measures. In the building material naturalness experiment, respondents from Norway, Finland, and Slovenia rated the naturalness of 22 common building materials. In the stress in office-like environments experiment, test subjects were stressed then allowed to recover over a period of 75 minutes while multiple objective indicators of stress were monitored. Subjects were tested in offices using two types of wood with very different characteristics (dark and light colour, distinct visible grain patterns) found in two wood species likely to be used for indoor furniture.

1.2 Hypotheses

1.2.1 Building material naturalness

The naturalness study hypotheses test building user's perceptions of the common building materials to understand how they perceive material naturalness linked to material type, presentation, and processing. The tested hypotheses were:

1. Respondents will recognise less processed materials as more natural than processed materials
2. Respondents will identify wood and stone as natural consistently, while other materials will be perceived as natural less consistently
3. Respondents will be consistent in their identification of natural materials and material naturalness
4. Respondent perceptions of building material naturalness will be consistent in different European countries

Testing these hypotheses provides a stronger foundation for understanding the link between a connection to nature felt through building material use in the built environment. Identifying materials perceived to be natural may help building designers better reflect nature and natural processes in the built environment in an effort to bring the positive effects of nature indoors.

1.2.2 Human stress and stress recovery in office-like environments

The three hypotheses of the human stress and stress recovery in office-like environments study were focused on determining if a stress moderating effect was present in offices with wood furniture compared to an office with non-wood furniture. The hypotheses tested were:

1. Cortisol concentration will be greater in the control environments with white furniture than in the wood furniture environments with light and with dark coloured species.
2. Maximum stress during the response period will be greater in the control environments than in the wood furniture environments for each type of wood furniture tested.
3. Recovery from maximum stress during the response period will be greater in the wood environments than in the control environments for each type of wood furniture tested.

Hypotheses one tested the theory that the presence of wood in an office space can produce reductions in overall stress levels. Hypothesis two tested the theory that the presence of wood in an office space can reduce the response to stress by reducing the maximum stress experienced. Hypothesis three tested the theory that recovery from stress will occur more rapidly in offices with wood furniture.

1.3 Objectives

The overall objectives of this study were to investigate the potential for wood use to be implemented as a stress mitigation intervention in offices, following the principles of biophilic design which relies on including nature in the built environment. This overall objective divided into three parts: a literature review, an investigation into user perceptions of building material naturalness, and a study of stress mitigation and recovery in office-like environments.

1.3.1 Literature review

The objective of the literature review was to collect and analyse the relevant literature on human stress in buildings, methods for observing reactions to stress experimentally, and previous studies conducted on the relationship between indoor wood use and human stress in order to understand the current state of the art, analyse gaps in the research, and plan future experiments to address those gaps.

1.3.2 Building material naturalness

The objectives of this study were to gain an improved understanding of user perceptions of building material naturalness. It was of great interest to determine if there was a consensus regarding the naturalness of common building materials such as wood, stone, brick, metals, plastics, etc. in multiple location in Finland, Norway, and Slovenia, and if some materials were consistently considered more natural than others.

1.3.3 Human stress and stress recovery in office-like environments

The objectives of this study were to design and administer an experiment that would allow researchers to effectively assess stress responses and recovery and compare those responses between office-like environments with and without wood furniture and of wood with different characteristics (e.g., colour, grain pattern, etc.).

2 LITERATURE REVIEW

This study included a detailed overview of studies that investigated the relationship between indoor built environments and human well-being. The findings summarised below were published in Burnard and Kutnar (2015), Burnard et al. (2017), and Burnard (2017) where the needs of future developments in the field were emphasised.

The built environment has a strong impact on both human and environmental health. Buildings and the infrastructure surrounding them consume great quantities of materials and energy during construction, operations, and eventual deconstruction at the end of the buildings life (Sinha, Gupta, and Kutnar 2013). Accepted measures exist and are widely used for analysing the environmental impacts of buildings and the materials and activities surrounding them such as life cycle costing and life cycle assessment (ISO/IEC 2006). As with environmental impacts, the built environment affects the people who use it in a variety of ways including, psychologically, socially, and physiologically. However, unlike the environmental impacts of the built environment, methods for understanding how buildings impact their users are not currently as well established.

Human health impacts in buildings stem from different elements and aspects of the building itself. These include the environment and location of the building, its design, materials, maintenance, accessibility, safety, and the management of the building (in terms of thermal comfort, lighting, etc.). Certain health impacts are easier to understand, and control, than others. For example, emissions from materials (such as formaldehyde) in buildings are readily assessable and limits are placed on these emissions by legislation in many places, including Europe and North America (European Comission 1992; Environmental Protection Agency 2016). Emissions measurements, though, are an indirect measure of the impact buildings have on human health impact, and are focused on preventing harm.

Harm prevention is an incredibly important aspect of building design, maintenance, and management, but modern building design paradigms are pushing beyond preventative measures and are beginning to incorporate both environmental and human health interventions that are intended to create positive effects (du Plessis 2012; Mang and Reed 2012; Dolan, Foy, and Smith 2016). For building users, these positive effects include health and behaviour impacts, which can translate to reduced pressures on health care systems, better job performance, and more time at work (Danna and Griffin 1999).

2.1 Health impacts of buildings

There are a variety of suggested frameworks for understanding and mitigating the negative effects buildings can have on occupants. When negative human health and well-being effects associated with spending time in built environments manifest, they do so in several ways ranging from increased time away from work, greater stress, reduced work performance, and direct health impacts. Briefly, these effects may be:

- Symptoms of illnesses: frequently observed as a variety of potentially connected symptoms often referred to as sick building syndrome (SBS) (Finnegan, Pickering, and Burge 1984).
- Psychophysiological well-being: especially, increased physical or social stress and a reduced ability to recover from stress (Rice et al. 2006; Fell 2010; Nyrud and Bringslimark 2010; Burnard and Kutnar 2015; Burnard 2017).
- Directed attention deficits: reduced ability to recover from focusing one's attention (Hartig et al. 1997).
- Ergonomic problems: musculoskeletal issues related to a lack of ergonomic interventions (Attaianese and Duca 2012)

The links between elements of buildings and the effect imparted on building users is not always clear, and in many cases a combination of elements are likely to jointly contribute. Furthermore, because place and local traditions play a role in how users perceive their environment, the effect of different design decisions may vary between places. While culture may impact how users perceive their built environment, perceptions of building material naturalness are unlikely to vary significantly (Burnard and Kutnar 2015). The combination of material use and design choices that reflect natural environments are important aspects of imparting positive health impacts for building users. Beyond perceptions, material selection also has direct effects on health impacts in the built environment, especially related to indoor air quality.

Natural materials, and the adhesives, coatings, other treatments used on them, release VOCs into the environment (Jensen et al. 2001; Manninen, Pasanen, and Holopainen 2002; Gallego et al. 2009). The amount and type of VOCs vary based on species, treatment, and product (cf. Bulian and Fragassa 2016). Regulations limiting the type or amount present in products used in buildings exist in many places, and are often further limited when green building systems are followed (Bulian and Fragassa 2016). Understanding the performance of natural materials in terms of fitness for use (e.g., structural suitability), their environmental impact, and their potential for contributing to positive health impacts in the built environment is critical for developing building paradigms that focus on positive impacts, instead of minimising negative impacts.

2.1.1 Psychophysiological well-being

As stress is the main focus of this research, psychophysiological well-being is presented here in more detail because stress and its related effects are most closely related to this health concern. Psychophysiological well-being can be considered as a state of a network of interdependent mental, emotional, and physiological systems (McCraty et al. 2009). Within this framework, the places people spend their time can affect their well-being by interacting with each system in the psychophysiological network. VOCs and other contaminants in the air directly impact physiological systems, which, in turn, affect mental and emotional state. Similarly, perceptions of the environment impact emotional and mental states and cause direct physiological impacts. Physical aspects of the built environment such as ergonomic function, safety, and accessibility also affect an individual in this framework.

The benefits that may be imparted by ones built environment include:

- reduced psychophysiological stress, the ability to cope better with stressful events and situations, and increased recovery from stress
- reduced time away from work due to illness
- increased connection with and care for the natural environment
- support for increased social cohesion
- support for more activity in typically sedentary lifestyles

These benefits and others can be imparted by user perceptions of materials, building design and ergonomic interventions, views and inclusion of nature in the built environment, and material properties affecting indoor air quality, thermal comfort, etc.

Restoration

In order to improve occupant well-being important design decisions must be made which balance occupant needs and health with other goals such as environmental impacts and design aesthetics. To achieve these goals designers must understand the relationship between psychophysiological well-being and restoration then implement design strategies that bring those issues to the forefront in their work. Many restoration theories stem from the field of environmental psychology and have helped to lay the foundation for new building design paradigms that emphasize occupant health, nature and sustainability. Furthermore, these building design paradigms offer an opportunity for increased wood use, because they are frequently based on including elements of nature in the built environment and wood is widely perceived to be natural (Burnard et al. 2017).

Hartig (2004) defines restoration as a process of renewal that replenishes a depleted social, psychological or physical resource. These resources have most often been depleted by an individual's effort to adapt to their environment (Hartig 2004). Early restoration theories focused on recovery from psychophysiological stress (Ulrich et al. 1991) and attention restoration (R. Kaplan and Kaplan 1989). Psychophysiological stress recovery theory posits that natural environments, and even views of these environments, will aid recovery from stressful events, including psychological stress and physical stress (e.g., recovery from surgery) (Ulrich 1984; Ulrich et al. 1991). Attention Restoration Theory (ART) focuses on understanding how individuals replenish their ability to exert attention on common tasks, such as those at the workplace that require directed attention (Hartig et al. 1997, 2003; Herzog et al. 1997; S. Kaplan 1995; R. Kaplan and Kaplan 1989) Though many experiments related to ART and psychophysiological stress recovery have focused on outdoor environments (or, views of outdoor environments) some experiments have examined bringing nature into the built environment. For example, a recent study examined the effect the presence of plants in an office-like environment has on attention capacity and found participants performed better in the presence of plants after performing a task approximately 25 minutes in the test room, but not upon entering the test room (Raanaas et al. 2011). In an extensive review of the psychological benefits of indoor plants Bringslimark, Hartig, and Patil (2009) determined that although the evidence suggests indoor plants can provide psychological benefits, the heterogeneity amongst the methods and results may imply the benefits are contingent on the context of the encounter with indoor plants and the participants in the experiment. These concerns extend to experiments with wood or other natural materials indoors.

Many studies have found empirical evidence to support these theories but the theories themselves remain open to elaboration as more evidence is collected regarding the restorative effects of nature (Hartig 2004). Studying the effects of wood on attention and psychophysiological stress restoration in the built environment may identify the characteristics of wood that are important to creating restorative effects, provide guidance on how to use wood to best achieve restorative effects in different indoor environments (e.g., offices, schools), promote increased use of renewable materials in buildings thereby reducing environmental impacts of buildings, as well as other outcomes.

2.1.2 Factors impacting well-being in buildings

The primary factors that impact human well-being in the built environment are related to materials, building and product performance, ergonomics, user perceptions of their environment, and the activities users perform in buildings.

Many aspects of each factor contribute to the impact felt by building users. For example, the material (e.g., an exposed wood beam) can be perceived by the user to impart safety (as a structural element), warmth (in colour and thermal comfort), restoration (associated with nature, cf. Burnard and Kutnar 2015); will have specific properties related to acoustics, thermal comfort, lighting, VOC emissions, etc.; and may be functionalised beyond its basic intent (e.g., supporting other elements of the building). These factors can be influenced by processing, maintenance, natural processes (such as decay, changes in colour), etc.

Material and product related

Material and product related factors that impact occupant health are considered to be those that are directly related to the material, product components, and processes. Wood and other bio-based materials are known to contain and emit VOCs and other contaminants as they go through drying processes (natural or otherwise). In recent years, formaldehyde has been a primary concern and has been limited by statue in many areas (e.g., by the Environmental Protection Agency (EPA) in the USA (Environmental Protection Agency 2016), by the European Commission in EN 120 (European Comission 1992), and other agencies worldwide).

VOC emissions from wood and other bio-based materials are biogenic, and are part of natural processes. The amount and type of emissions are dependent on species and affected by processes such as drying or thermal treatment. For example, differences in the types and quantities of emissions varied between air dried and heat-treated Scots pine, as reported by Manninen, Pasanen, and Holopainen (2002). It is possible for reactions to occur as wood dries causing emissions of compounds not originally present in the material as well (Milota 2000). Subjecting wood to thermal processes (e.g., drying, heat-treating, thermal-mechanical treatments) before use can limit the amount of emissions after installation (Milota, Mosher, and Li 2007).

Emissions released by composite products, especially those of glued composites using adhesives with formaldehyde are also a major concern as they are present to a great degree in the furniture used in buildings, and other building components (Huang and Li 2008; Jang, Huang, and Li 2011). While alternatives (e.g., soy-based adhesives) are under development, their performance often suffers in terms of strength or susceptibility to water (Schwarzkopf, Huang, and Li 2010; Jang, Huang, and Li 2011).

Other processes impose similar concerns: wood preservatives, fire retardants, and coatings often contain contaminants, which may be emitted into buildings or outdoor spaces (Yu and Kim 2012). The inclusion of these contaminants in building products impedes their use in recycling schemes, as well (Yu and Kim 2012).

Processes that affect appearance (such as some coatings or mechanical processing that can obscure recognisability as a natural product) are likely to reduce the ability of occupants to gain restorative effects from the materials (Burnard and Kutnar 2015). Similarly, these processes are likely to impact user preference for materials as well, which can have similar psychological effects on building occupants. Coatings and other treatments also impact the degree of perceived warmth (a haptic response felt by users when touching a material) (Bhatta and Kyttä 2016). In principle, when a material feels warmer at a lower temperature than another, energy used to heat the material (e.g., flooring) can be saved while maintaining acceptable levels of thermal comfort (Bhatta and Kyttä 2016).

Material use in buildings

The performance of materials in buildings relies on a complex system that includes building systems management that control electronic and mechanical components, materials, use patterns, outdoor weather, building design, and more. Bio-based materials can play many roles in building performance. Some recent research trends have been to functionalise wood and wood products, along with other bio-based materials, to provide improved material properties such as fire retardancy, hydrophobicity, and resistance to weathering (Petrič 2013).

In the presence of moisture, bio-based materials can be a nutrient source for fungi in build environment (World Health Organization Europe 2009). Fungi can have a variety of negative effects ranging from damage to the buildings structure (in the case of wood-rotting fungi) and can become airborne potentially harming building users (World Health Organization Europe 2009). Fungi, moulds, and associated bacteria are known to emit VOCs (often termed microbial volatile organic compounds – MVOCs), allergens, and a variety of toxins (World Health Organization Europe 2009; Sahlberg et al. 2013). However, evidence that inhalation of these substances cause human health problems remains unconvincing (as opposed to evidence that ingestion of fungi causes health problems) according to Terr (2009). While studies continue to examine airborne toxins related to moisture and fungi in the built environment, experimentally controlled studies are impossible due to health concerns (Terr 2009). Nonetheless, limiting the fungal growth (and other phenomena related to moisture and dampness) in buildings should be a key aspect of material selection, building design, and construction methods.

The varying colour, treatments, and use of bio-based products indoors impacts lighting needs and the visual comfort of spaces in buildings (Jafarian et al. 2016). There is an opportunity to optimise artificial and day lighting, as well as occupant visual comfort by using wood indoors of various colours, patterns (imparted by grain or designed), and amounts to alter brightness, colour temperature, perceived glare, and other attributes through intelligent use bio-based products (Jafarian et al. 2016).

Noise annoyance is widely associated with stress in buildings (Rashid and Zimring 2008). Ambient noises sources, such as intelligible speech in offices, and occasional noise peaks such as telephone rings, are a source of noise annoyance in buildings that can increase stress (Graeven 1975; Kjellberg and Landström 1994). Building design and material selection are useful tools to reduce noise annoyance buildings (Amundsen, Klæboe, and Aasvang 2011). Importantly, bio-based materials, including flax, cellulose, wood wool, and cork have been shown to be effective in providing good acoustic performance, even as recycled components that may further reduce environmental impacts (Asdrubali 2006).

Human Factors/Ergonomics

Human Factors/Ergonomics (HFE) is a scientific discipline that is itself primarily concerned with human well-being and performance; it seeks to optimise systems to maximise its concerns (Dul et al. 2012). HFE enhances well-being by implementing design changes and interventions in buildings, products, and systems to reduce negative impacts on users. The types of interventions may relate to:

- safety (e.g., railings in bathrooms, along walkways and stairs, etc.),
- accessibility (e.g., ramps, room size, optimising worker movement in an office or factory), or,
- activity (e.g., reducing time in sedentary positions while at work, providing activities to mitigate the musculoskeletal effects of excessive sedentary time, for example, lower back pain).

There are many opportunities for bio-based materials to play a role in these interventions, and the overall well-being goals are well aligned with optimised wood use in buildings.

Using wood as a safety intervention for the elderly can help users navigate and safely use bathrooms (Verma 2016). The colour contrast of wood and typically white porcelain components of bathroom environments helps users (especially those with diseases like Alzheimer's) to more easily recognise and use components of bathrooms (Verma 2016). Similarly, natural materials may be used for a variety of interventions including ergonomically designed furniture, built-up handles on utensils, railings, ramps, etc.

Design related

The variety of HFE, material and product, and performance factors discussed above require an overarching framework to produce positive human health impacts. Several design paradigms exist for including elements of nature in the built environment, including biophilic design (Kellert 2008), restorative environmental design (RED) (Derr and Kellert 2013), regenerative design (du Plessis 2012; Mang and Reed 2012), restorative environmental and ergonomic design (REED) (Burnard, Schwarzkopf, and Kutnar 2016; Burnard 2017). These design paradigms each place emphasis on including nature in the built environment, however except for REED, the focus is less on material choices and more on access to nature through views of windows, water features, plants, etc. The specifics of material selection are often overlooked and relegated to concerns of cost and environmental impact. While these concerns are valid, creating positive impacts requires making evidence based decisions for a variety of design choices.

2.2 Studies examining human psychophysiological responses to wood

Though there have been relatively few studies directly examining the psychophysiological effects wood in the built environment has on people published in English language literature, they come to a similar conclusion: wood has a generally positive effect on occupants. The studies discussed here represent a representative published English-language scientific work on the topic. The studies all have examined biological indicators of psychophysiological stress or recovery from it and therefore provide insights into how wood use may provide benefits for stress reduction or improved recovery from stress. All but one of the following studies reported finding beneficial health impacts of wood in the built environment. In each case, the use of actual-size test environments allows easier application in practice. Many of the studies were done with limited sample sizes, however, they provide an impetus for further work in the field and a foundational framework for future studies.

Tsunetsugu et al. (2002) examined psychophysiological responses of subjects exposed to decorative wood applied to living room environments. The most basic room included white walls, with wood flooring, two covered (with drapes) windows, a coffee table, and one plant. The other room was identical to the basic room, but also included decorative wall and ceiling treatments made from wood. Ten subjects were preconditioned in a third room with a decorative wood treatment on the walls that was otherwise identical to the two test rooms. Baseline heart rate and blood pressure measurements were taken in this room. All subjects were exposed to two test environments: the basic room and the decorated test room. Subjects were randomly assigned to initial test rooms, but were exposed to both rooms consecutively. While heart rate and blood pressure decreased in the room with decorative wood application, the sample size was small and a potential serial effect could confound the findings. Furthermore, the objectives of the study were not clearly defined, and therefore not clearly ascertainable in the studies findings, which makes interpretation of the findings and determining their applications challenging. Increasing sample size, clearly defined objectives and study outcomes that reflect them are critical in the early stage of defining a nascent research field.

Sakuragawa et al. (2005) assessed how material preference impacts blood pressure when viewing those materials. In this study, subjects were asked about their feelings for steel and wood then exposed to a white steel wall and a wood wall in a random order. The study found subjects who reported liking steel maintained stable blood pressure readings during exposure to the steel wall. Those who reported disliking steel had increased blood pressure when exposed to the steel wall. Blood pressure decreased for subjects who reported liking wood when exposed to the wood wall. For those subjects who reported disliking wood blood pressure neither increased or decreased when exposed to the wood wall. The walls were presented in an otherwise empty room, with no environmental context. The small sample size and the possibility of serial effects in this study limit inference of any findings. Additionally, the subjects were exposed to the experiment topic in the questionnaire before the test began. Avoiding the serial effect by using a within-subjects design on only two treatments for each subject could have improved the findings. Alternatively, using three subject groups (one control and one for each treatment) could have strengthened the findings as long as the sample sizes were increased. Notably, however, this study revealed how preference for materials might impact psychophysiological responses to different environments.

Tsunetsugu, Miyazaki, and Sato (2007) assessed psychophysiological responses to different quantities of wood in a replicated living room environment. Four rooms were prepared for the experiment, a practice room to familiar the subjects with the procedure of the experiment and three test rooms treated with different amounts of wood coverage. Each test room was designed to appear as a real, Japanese-style living room and was treated with 0 %, 45 %, and 90 % wood coverage. Heart rate and blood pressure were assessed as psychophysiological indicators of stress and health for 15 subjects during and after 90 seconds of exposure in each environment. Subjects were also asked to provide ratings of each of the three experimental environments. The 45 % covered room was the most favoured, and diastolic blood pressure was lower, but heart rate was higher in this room than the 0 % room. The 90 % room yielded the lowest blood pressure measurements, but subjects registered increased heart rates in the room. The short exposure time in each room provides only a small window into the immediate response of the subject to the environment. In this context, the results may not be indicative of the effect of spending significant time in indoor environments with wood. Though the sample size was small, the lack of correlation between preference and physiological response contradicts the preferential findings in Sakuragawa et al. (2005).

In the most robust study on the topic Fell (2010) assessed sympathetic indicators of the autonomic nervous system (ANS) stress responses for 119 subjects in four different office-like environments. In this factorial study subjects were randomly assigned to only one room. The room treatments were: control (with non-wood furniture, and no plants), non-wood furniture with plants, wood furniture without plants and wood furniture with plants. Subjects were monitored by an electrocardiogram and for electrodermal activity over three intervals: during a period of ten minutes prior to the test to determine a baseline reading, throughout the test, and for a ten-minute recovery period after. To induce stress subjects were given a Paced Auditory Serial Addition Test (PASAT, Gronwall 1977), which is considered a light stressor. Directly after the test period subjects were asked to complete an environmental satisfaction questionnaire. The electrocardiogram provided analysis of cardiovascular responses to stress including inter-beat interval and heart rate variability. Electrodermal monitoring allowed for analysis of three stress responses: skin conductance levels, frequency of non-specific skin responses (F-NS-SCR) and amplitude of non-specific skin responses (A-NS-SCR). Measurements were compared between treatments during the baseline period (pre-test), testing period, and recovery period (post-test). Cardiovascular responses were not found to be significant in this study. However, there was strong evidence F-NS-SCR values were lower during the pre-test and recovery periods in the room with wood furniture and no plants, and some evidence of lower values during the test period in the same room. The study also examined the effects of indoor plants on stress responses, but neither a main effect nor an interaction effect were discovered. This study provides the most robust examination of the psychophysiological effects of wood in the built environment. However, to better account for individual variations in stress responses a within-subjects design may have been useful. Similarly, profiling the individual's mood state and using a stronger stressor may have strengthened the findings.

Nyrud, Bysheim, and Bringslimark (2010) examined restoration more directly in their study of interior wood treatments in hospital recovery rooms. This study compared recovery times, pain medication use, blood pressure and self-reported measures of pain and stress of 197 orthopaedic patients in three different room types. Each room had either a view of nature, was treated with a piece of art, or was treated with a decorative wood element. No significant differences were found between rooms for any measure. Connecting these findings to Ulrich's 1984 study of hospital recovery where views of nature alone were found to have positive impacts on recovery raises questions about the amount of nature that must be visible to impact recovery times. That is, to what degree must nature be present to aid recovery times and reduce pain and are particular elements of nature more or less beneficial than others?

Ikei, Song, and Miyazaki (2017) recently reviewed 41 studies on the physiological effects of interacting with wood through audio, visual, olfactory, and haptic stimulation as well as forest bathing. Their work concluded that despite the many studies, limited sample sizes, non-diverse participants, and single stimulant (e.g., only olfactory or only visual stimulation) tests may not reflect the actual effects of wood in the built environment accurately. The authors note a range of physiological indicators and multiple stimulants should be used in capture the full physiological effect of interacting with wood.

2.3 Experimental measurement of human health indicators

Monitoring human well-being in the built environment requires understanding how humans interact with their surroundings, how perceived and physical stress are affected by buildings, how materials and building systems management impact indoor air quality, and many other aspects of the complex relationship between humans and the built environment. In many cases, common monitoring systems are indicative or indirect measurements of impacts on occupants and therefore difficult to directly relate to health impacts.

For example, measurements such as temperature, relative humidity, lighting, and air flow are straightforward to collect and interpret, but determining their impact on human health is more challenging. Upper and lower limits are generally suggested for thermal comfort indicators (e.g., temperature, relative humidity) in standards such as ISO 7730:2005 (ISO/IEC 2005). These limits are expected to provide an acceptable level of comfort, but the specific contribution of materials to these values is not well known. Properties of bio-based materials such as thermal capacity or latent heat impact indoor environments, and if better understood may be able to be used to reduce mechanical interventions in the built environment (Kraniotis et al. 2016).

Direct measurements of human well-being are more difficult to collect. Subjective measures of well-being may be derived by collecting user mood and comfort status, reports of illness, sick days taken, etc. but require human input and may vary greatly between users. Biological indicators of health and well-being (particularly stress and activity) are useful indicators of the actual state of building users, but are more difficult and occasionally intrusive to collect. This difficulty, and the nascent state of the field, have led to relatively few studies into human health and well-being impacts of materials or buildings (Burnard and Kutnar 2015).

Monitoring recovery from stressful events is one way to explore and assess the restorative properties of indoor environments. However, stress is not a rigidly defined concept and there is disagreement regarding its precise definition (Burchfield 1979; Cohen, Kessler, and Underwood-Gordon 1995). Despite these differences Cohen, Kessler, and Underwood-Gordon (1995) note how various definitions all refer to an interest in the process in which environmental demands exceed ones' adaptive capabilities and lead to psychological and physiological changes in an individual. Excessive activations of these responses are worrisome because they may place individuals at risk for disease (Cohen, Kessler, and Underwood-Gordon 1995; Lucini et al. 2002; Gaab et al. 2003).

Cohen, Kessler, and Underwood-Gordon (1995) distinguish between three traditions in assessing the role of stress, and note each makes different assumptions and therefore uses separate methodologies for measurements. These traditions are (Cohen, Kessler, and Underwood-Gordon 1995):

- Environmental tradition - focuses on experiences triggered by one's social, natural, and cultural environment, which are objectively associated with substantial demands on the individual to adapt to the environment and uses environmental demands, stressors, or events as components of analysis.
- Psychological tradition – scrutinizes an individual's subjective assessment of their ability to cope with the adaptive demands of specific events using appraisals or perceptions of stressfulness in specific situations as metrics of stress level.
- Biological tradition – researchers determine stress levels by monitoring the activation of specific physiological systems established as responding to adaptive demands on the individual and uses metrics of the activity for analysis of stress level.

Both the psychological and biological traditions have been employed to measure stress recovery in restorative environments. The methods associated with these traditions are more readily assessed in laboratory settings, and biological methods provide measures suitable for inferential comparisons. The environmental tradition is less useful in laboratory experiments because previous stress events are hard to place in relation to restorative environments and rely on self-reported assessments of the events, often at a much later date.

Psychological measures are subjective and rely on respondent assessment of their own situation. Subjective measures in this field are inherently challenging to make causal inferences from, but provide context and suggest direction for qualitative analysis (Cohen, Kessler, and Underwood-Gordon 1995). On the other hand, biological methods for assessing stress often rely on monitoring the sympathetic and parasympathetic activity of the ANS and the output of the hypothalamic-pituitary-adrenocortical axis (HPA) of the endocrine system (Cohen, Kessler, and Underwood-Gordon 1995; Kirschbaum and Hellhammer 1994; Sztajzel 2004). Though physiological responses to stress reveal themselves in a variety of measurable ways, these metrics are critical because they are the primary indicator of how stressed an individual becomes, and also how quickly and fully an individual recovers from stress.

ANS responses to stressors include increased output of epinephrine, norepinephrine, increased blood pressure, heart rate, sweating, and constriction of peripheral blood vessels (Cohen et al. 1995). Methods for monitoring these responses have been employed in studies examining the effect wood has on occupant stress (Tsunetsugu, Miyazaki, and Sato 2002; Sakuragawa et al. 2005; Tsunetsugu, Miyazaki, and Sato 2007; Fell 2010).

The HPA response is to release hormones, which help the body maintain homeostasis when presented with a stress event (primarily cortisol, a corticosteroid, in humans) (Kirschbaum, Pirke, and Hellhammer 1993; Kirschbaum and Hellhammer 1994). Salivary free cortisol quantity is considered an effective, non-invasive measure of the HPA response to stress and therefore is useful to determine individual stress levels (Kirschbaum, Wüst, and Hellhammer 1992; Kirschbaum, Pirke, and Hellhammer 1993; Kirschbaum and Hellhammer 1994; Kirschbaum et al. 1999; Gaab et al. 2003; Hellhammer, Wüst, and Kudielka 2009). Kirschbaum et al. (1992; 1993; 1994; 1999) have extensively explored the HPA response to stress, and have established cortisol levels as an effective measure of the response. Hellhammer, Wüst, and Kudielka (2009) concluded salivary cortisol is useful as long as the researchers are aware of possible sources of variance in salivary cortisol and possible confounding variables are properly accounted for. These include sex, psychiatric health, and smoking (Hellhammer, Wüst, and Kudielka 2009). Furthermore, cortisol levels naturally follow a circadian rythem throughout the day with peak release occurring soon after awakening and diminishing slowly throughout the day to their lowest levels in the evening (Dickerson and Kemeny 2004; Hellhammer, Wüst, and Kudielka 2009). Dickerson and Kemeny (2004) note conducting experiments during the same time period for all participants and later in the day is one method to overcome this challenge. Furthermore, including a no-stressor control group or using within-subject experimental design are also suggested (Dickerson and Kemeny 2004). In addition to the circadian release cycle of cortisol, regular pulsatory cortisol releases do occur, but are quite stable within individual subjects suggesting a within-subject experimental design may compensate well for this attribute (Chrousos and Gold 1998).

Salivary free cortisol can be determined by assessing saliva samples gathered with a simple mouth swab, which can be stored and assessed at a later time (Gaab et al. 2003). Additionally, saliva samples are non-intrusive and practical for taking repeated measurements in a short period of time. Assessment of cortisol concentration in saliva can be determined by immunoassay methods described elsewhere (Dressendörfer et al. 1992).

While monitoring and assessing stress in any experiments, it is important to remember stress manifests itself in many ways, and the wide variety of autonomic and endocrine activity indicators used to monitor stress levels do not always correlate with each other. However, salivary free cortisol levels are an effective indicator of laboratory and real-world stress levels and have been found to correlate well with many other indicators of stress (Lucini et al. 2002; Dickerson and Kemeny 2004; Hellhammer, Wüst, and Kudielka 2009). Despite this, salivary free cortisol levels have not been used as an indicator of stress in experiments studying the psychophysiological responses to wood. This method has been used in monitoring restoration in outdoor environments (Park et al. 2007; Tyrväinen et al. 2014) and extensively in other stress related experiments (Kirschbaum, Wüst, and Hellhammer 1992; Kirschbaum, Pirke, and Hellhammer 1993; Kirschbaum and Hellhammer 1994; Lucini et al. 2002; Gaab et al. 2003; Hellhammer, Wüst, and Kudielka 2009).

2.4 Using wood to enhance human health in the built environment

Wood is an ideal material for enhancing human health in buildings because it satisfies the key general design tenets of modern building paradigms that provide positive impacts: sustainability and a connection to nature. Furthermore, research investigating psychophysiological responses to wood in the built environment supports the idea that indoor use of wood has positive health implications for occupants. Wood from healthy, well-managed forests is a renewable material, and provides carbon storage (Hashimoto et al. 2002). It is unsurprising such a product, when used in appearance applications, also provides a connection to nature (Masuda 2004; Rice et al. 2006; Nyrud and Bringslimark 2010; Nyrud, Bringslimark, and Bysheim 2013).

Wood is also an abundantly available material. The United Nations Food and Agriculture Organization (FAO) reports 30 % (~1.2 billion hectares) of the worlds forested area is used specifically for production purposes (FAO 2010). Another 949 billion hectares is designed as multifunction, which may include production purposes (FAO 2010). Usage from these forests includes industrial roundwood destined for wood products, fuelwood, and non-wood forest products. The majority of harvests from forests in Asia and Africa are used for fuelwood, while in Europe, North America and Oceania fuelwood harvests account for less than 20 % of the total (FAO 2010).

Furthermore, wood is known to sequester carbon throughout its lifetime when product lifetimes are sufficiently long (Hashimoto et al. 2002; Tonn and Marland 2007; Salazar and Meil 2009). In many industrialized countries carbon storage in wood is greater than carbon released by activities inclusive of harvest and disposal and all steps in between (e.g., production, transportation) (Hashimoto et al. 2002). Therefore, effective use of wood products can reduce the amount of carbon released to the atmosphere. Correspondingly, well-managed forests provide a continuous supply of sustainable materials offering a variety of potential uses in the built environment.

Wood is an excellent building material because of its excellent strength to weight ratio and the variety of forms in which it can be used (e.g., in log form, lumber form, in fibre form, and in combination with other materials). In the United States, more than 90 % of residential buildings are wood-framed and Japan is not far behind (Sinha, Gupta, and Kutnar 2013). However, wood used in housing is often a concealed structural component thereby limiting occupant interaction with it. Furthermore, wood use in non-residential construction is considerably less common than in residential construction (O'Connor et al. 2004). Beyond structural uses, wood is also an excellent architectural material for furniture and in decorative applications, and is used in many forms such as solid wood, wood-based composites like plywood, particleboard and medium density fibreboard. Though exposed wood is present to some degree in many indoor environments, there are opportunities for greater utilization, which may contribute positively to occupant health (Rice et al. 2006; Fell 2010; Nyrud and Bringslimark 2010). Increasing wood use indoors by, for example, using exposed massive timber (cross laminated timber) may also offer improve indoor thermal comfort by buffering indoor temperature variations (Hameury and Lundström 2004). Some common interior uses of wood are tables, chairs, cabinetry, desks, flooring and moulding.

Furthermore, wood is generally viewed positively and evokes feelings of warmth, comfort, relaxation, and is reminiscent of nature (Rice et al. 2006; Nyrud and Bringslimark 2010; Fleming, Wiebel, and Gegenfurtner 2013). Aspects of wood connecting humans to nature include recognition as a natural product, pattern, and colour (Masuda 2004; Rice et al. 2006; Nyrud and Bringslimark 2010; Fell 2010).

Though wood is often available in a variety of natural colours and patterns, the yellow-red hue with relatively low contrast is common, and provides a positive, agreeable and pleasant image

(Masuda 2004). Colour contrast in wood is due to naturally occurring colour differences between earlywood and latewood, knots, and other natural wood features. In addition to the colour contrast provided by these features, they also construe pattern to the viewer (Figure 1). This aspect of wood also contributes to the positive and agreeable image of wood and fits well with the fascination principle of restorative environments (Masuda 2004). The presence of knots in wood products, however, demonstrates cultural differences in our perception of it as a pleasing material. In Japan, the presence of knots is considered to diminish its purity, while in North America knots are considered natural and rustic (Rice et al. 2006).

Figure 1: Grain pattern exemplified by in Douglas fir (Pseudotsuga menziensii). The lack of geometric shapes and consistent patterns may lead viewers to consider it more natural.

Though not specifically mentioned as a biophilic material in *Biophilic Design* (Kellert 2008), Fell (2010) notes that of the 30 images used as examples of biophilic indoor environments 25 images feature wood. Furthermore, wood can address each of the six biophilic design tenets discussed in the previous section:

1. Environmental features – wood provides a direct link to nature, as it is a recognizable natural element.

2. Natural shapes and forms – patterns in wood grain are naturally developed and wood can be used in forms representative of the material as a living organism (such the tree-like columns in Figure 2, which serve both structural and aesthetic purposes).

3. Natural patterns and processes – grain patterns, colour spectrum, and the presence of knots evoke natural patterns and process (Figure 1).

4. Light and space – wood naturally has colour diversity and can be stained in a variety of colours without losing its familiarity as a natural product, and it can easily be deployed in products of various sizes to address space concerns.

5. Place-based relationships – Using locally sourced wood products can evoke a regional connection to nature, historical and regional building methods, which utilized wood, may be imitated also.

6. Evolved human relationships with nature – Trees and wood have long been used as source for shelter, tools, transportation, and art.

2.4.1 Environments that may benefit from health focused design

There are many indoor environments in which occupants would benefit from shifting design decisions to create positive human health outcomes. Recent research has focused on offices, hospital recovery rooms, schools, and homes (Ulrich 1984, 1991; Tsunetsugu, Miyazaki, and Sato 2007; Fell 2010; Nyrud and Bringslimark 2010; Derr and Kellert 2013).

Office environments are considered to have an effect on occupational health (Danna and Griffin 1999). Emphasizing employee health is not only important to the individual, but also directly related to productivity and efficacy; Danna and Griffin (1999) cite work setting as an antecedent of well-being and health in the workplace. Though they do not specifically suggest restorative environments as a solution, the connection between healthy employees and productivity is made clear. Using wood materials, therefore, is a potential solution to help ensuring healthy and productive workers.

Hospital stays after cholecystectomy surgeries were studied in a Pennsylvania hospital between 1972 and 1981 to examine whether the view from the recovery room might influence recovery times as well as analgesic and anxiety medication use (Ulrich 1984). Ulrich (1984) found patients with a view of nature recovered more quickly and used less analgesic medication. No significant results were found regarding anxiety medication, except that analgesic dosages may have impacted the amount of anxiety medication taken.

A case study of four children's environments (three schools and one "learning environment") revealed the variety of ways restorative environmental design was implemented in schools and school-like settings (Derr and Kellert 2013). In these environments Derr and Kellert (2013) report finding many aspects of sustainable building such as energy reduction through passive and active solar systems, rooftop gardens, sustainable and local material use, use of recycled material, rainwater harvesting and even composting toilets. Similarly, the authors identified many biophilic features including, natural materials in the building construction and curriculum, direct exposure to plants, animals and water, connections to ecological place, exhibits including natural materials, natural forms and motifs, nature-based colour palettes, and the transformability of indoor and outdoor spaces – meaning spaces where children can interact with, affect, and manipulate their environments (Derr and Kellert 2013). Children generally reported positive feelings about their schools. Furthermore, the restorative elements of the environments served as potential learning opportunities. That is, the natural elements in the schools were directly used to teach lessons, but also as part of the environmental construct connecting the children to nature. By connecting children to nature at an early age, and reinforcing the human-nature connection sustainability principles may also be more readily embraced (Derr and Kellert 2013). The authors identified the need for more research to examine the impact restorative environmental design has on fostering enhanced understanding of the natural world and its processes. Identifying these benefits may provide children and students with increased learning capacity, reduced stress and improved overall well-being. Additionally, promoting a stronger connection to nature may inspire and motivate individuals to care for their environment.

2.5 Building design certification systems

Two recently developed standards attempt to reward design choices that may lead to positive human health impacts. The Living Building Challenge (International Living Future Institute 2016) and the Well Building Standard (International Well Building Institute 2017) both reward implementing biophilic design to promote health (amongst other organisational systems and policies). However, neither indicate the use wood (or other materials) as a method of achieving biophilic design goals. Where wood is mentioned in these standards, the context implies limiting either environmental harm by using certified forest products, or limiting human health impacts by prohibiting urea-formaldehyde adhesives in wood composites and limiting wood as a fuel source for heat. Nonetheless, photos of buildings with wood elements feature prominently in the image-heavy Living Building Challenge standard (International Living Future Institute 2016).

Both systems mention the concept of natural patterns when defining the implementation of biophilic. However, assessing the naturalness of the patterns or elements that implement them is not defined. It is important to understand how users perceive naturalness in order to meet the objectives of implementing natural patterns in the built environment.

2.6 Building material naturalness

In Western cultures, naturalness is perceived positively and is a favoured trait in some product categories, such as food (Rozin 2005; Rozin, Fischler, and Shields-Argelès 2012). Building material naturalness has been identified as a positive trait in broader perception and preference studies (Jonsson 2005; Rice et al. 2006). Preferences for nature, natural settings, and natural products have been well studied both generally and specifically for building materials (R. Kaplan and Herbert 1987; R. Kaplan and Kaplan 1989; S. Kaplan 1995; Rozin 2005; Jonsson 2006; Nyrud et al. 2010; Overvliet and Soto-Faraco 2011; Rozin, Fischler, and Shields-Argelès 2012). However, studies on perceptions of building material naturalness are limited. The studies that have examined building material naturalness directly have focused on the rea- sons for identifying the material as natural, or the underlying sensory input that causes an individual to identify a material as natural (Overvliet and Soto-Faraco 2011). With the growing interest in green building paradigms, biophilic design, and healthy buildings, there is an emphasized need to incorporate natural materials and to know from potential occupants which materials are considered natural.

Fleming, Wiebel, and Gegenfurtner (2013) note that people are extremely good at identifying broad material classes such as wood, plastic, or soap and that the materials we encounter belong to a natural class such as stone or fabric. The authors extend this finding, stating that humans make judgements about the perceived qualities of materials irrespective of the apparent class they fall within, but some material classes tend to be viewed as more natural than others (Fleming, Wiebel, and Gegenfurtner 2013). In one study, images of foliage, stone, water and wood were clearly considered more natural than images of fabric, glass, leather, metal, paper and plastic (Fleming, Wiebel, and Gegenfurtner 2013).

According to the participants of a series of focus groups conducted in Oslo, Norway, the amount of pro- cessing a building material had been through and the presence of additives in building materials diminishes the material's perceived naturalness (Nyrud et al. 2010). Similarly, Rozin found the transformations foodstuffs had undergone were an important aspect to user perceptions of their naturalness (Rozin 2005; Rozin, Fischler, and Shields-Argelès 2012). Overlivet and Soto-Faraco (2010) believe the concept of naturalness is multidimensional and hard to attribute to a single characteristic such as the degree of transformation. This may indicate that there are cultural or place-based aspects to one's assessment of naturalness despite the homogeneity in preference for natural landscapes and nature that Kaplan and Herbert (1987) have found across cultures.

3 MATERIALS AND METHODS

Three materials and methodology of three phases of this study are described here. In each phase, the underpinning elements of the final phase (the human stress in the built environment experiment) were explored and analysed to ensure the final results were robust and accounted for a variety of nuisance factors.

The literature review was conducted by examining relevant scholarly publications, books, and a PhD dissertation related to human stress, and human well-being in the built environment. The literature review was previously published in Burnard and Kutnar (2015) (Attachment 1). This work was later extended in a book chapter (Burnard 2017, Attachment 2).

The building material naturalness study was conducted by implementing a questionnaire-based survey in Finland, Norway, and Slovenia asking respondents to rate the naturalness of 22 building materials that were presented to them. The results of this study were previously published in Burnard et al. (2017) (Attachment 3).

The human stress in the built environment study consisted of a within-subjects experiment that examined the response to recovery from a stressor in rooms with wood and without wood furniture. Office-like environments with two types of wood (light coloured and dark coloured, each with clearly visible grain patterns) used to investigate differences between two very different types of wood.

3.1 Literature review

Critically evaluated articles examining human psychophysiological stress and wood in this review were sought in peer-reviewed English-language journals found in online databases. One PhD dissertation is included in the critical evaluation and three other studies are mentioned, which may demonstrate further interest in the field but are not published in peer-reviewed journals. The latter articles are mentioned for completeness, but do not offer qualified evidence for or against stress impacts in indoor environments with wood. Searches yielded four scholarly articles and the aforementioned PhD dissertation. The limited results of the search indicate that this field is in a nascent stage. It is therefore important to review the existing work and identify helpful results and troubling trends alike in order to improve future research in the field. The scholarly articles and book (R. Kaplan and Kaplan 1989) related to restorative environments were gathered through searches of scholarly databases. In addition to these articles, this review has been supplemented with information from two books published on biophilic design that represent the most robust collection of information on that subject. The framework articles related to restoration and environments (e.g., Ulrich et al. 1991; S. Kaplan 1995) are included as a foundation, which has been built upon by many other researchers—including those who have worked with stress and wood in the built environment. Other articles (e.g., Hartig et al.

1997; Hartig 2004) provide a framework for understanding and assessing perceptions of restorative environments. Finally, articles and books providing context for functionalising restoration theories in the built environment, especially work by Kellert (2008) and Wilson (2008) amongst others, are discussed. These books present little scientific evidence, but identify current and potential applications of the restoration theories. In these cases, they also provide context in which studies examining restoration in the built environment can be conducted. There are many more scholarly articles reviewing the use of biological indicators in psychophysiological stress experiments, and indeed robust review articles and meta-analyses of the research (cf. Dickerson and Kemeny 2004). Two articles are presented in more detail here to demonstrate useful methods to examine stress that are applicable to future studies examining human stress in the built indoor environment.

3.2 Building material naturalness

3.2.1 Materials

The naturalness study was conducted by administering a survey in Norway, Finland, and Slovenia to assess respondent perceptions of building material naturalness and if they differed between regions. The survey instrument was a paper questionnaire that asked respondents to assess the naturalness of 22 building materials used in European construction. The three non-demographic questions asked were (Attachment 4: Naturalness Questionnaire in English, Finnish, and Slovene):

1. Natural / not natural. Please consider whether the material specimens being shown are natural or not natural by evaluating each specimen visually. Consider the various specimens for only a few seconds each, and tick the answer that you think is appropriate.
2. The degree of naturalness. Please consider the extent to which you believe the various material samples are natural by evaluating each specimen visually. For each of the various material samples circle the number that best represents your perception of the material. Do not evaluate each sample for a long time, but select the answer that you think is correct immediately.
3. Ranking of material samples. Please rank all samples in relation to your assessment of the naturalness of each sample. Write down the sample number for the sample material you feel is **most natural in the first line**, and write the sample number for each other sample in order of decreasing naturalness.

The materials displayed for visual evaluation included wood and wood composites, stone, metals, plastics, textiles, and other materials (Table 1).

Table 1: Names and identification numbers of building material specimens assessed by respondents

Specimen ID	Specimen description
007	Oriented Strand Board (OSB)
113	Pine, planed, knots
158	Particleboard
193	Cork
210	Medium Density Fibreboard (MDF) (painted white)
235	Brick
292	Ceramic Tile
307	Woven fabric
321	Wood Plastic Composite (WPC), imitated growth rings
344	Pine, rough, clear of knots
401	MDF (painted white), imitated growth rings
420	Pine, planed, without knots
447	Steel, milled surface
469	Wool fabric
510	Stone tile
560	Painted Pine
615	Ash, Heartwood (HW), planed
642	Plastic, polished
712	MDF, plain
773	Steel (white)
823	Wallpaper, white
829	Leather, untreated

Physical specimens of each sample were presented in paperboard boxes that obscured the edges of the specimens so that only the face was readily visible (Figure 2). The dimensions of each material sample were 100 mm × 100 mm and between 10 mm and 20 mm thick (thickness varied on some specimens, such stone tile). The paperboard boxes were 115 mm × 115 mm × 45 mm. Specimens were numbered with three digit versions (e.g., with leading zeroes) of randomly selected numbers between 1 and 999 to allow respondents to identify the material on the questionnaire.

Figure 2: A material specimen as presented in its paperboard box (ash heartwood, specimen number 615)

The materials in the study included specimens with varying degrees of transformation from their raw state. Although a wide variety of building materials were included in the study, the selection of materials does not include all possible building materials. Limiting the number of materials made the task of assessing all specimens more manageable for respondents.

3.2.2 Methods

This survey employed a paper questionnaire to assess respondent perceptions of building material naturalness. The questionnaire was based on the measurement methodology described in Overvliet and Soto-Faraco (2011). However, following testing one section was removed because the testers complained it was too difficult, and that the entire questionnaire took too much time to complete, or simply copied their responses from another section providing no new information.

Questionnaire

The final questionnaire had four sections:

1. Binary decision task: for each material specimen, respondents were asked to indicate if the specimen was "Not Natural" or "Natural".
2. 7-point category scaling task: for each material specimen, respondents were asked to rate its naturalness from 1 to 7. The scale and instructions indicated that selecting 1 indicated the respondent considered the material "Not natural" and that selecting 7 indicated the respondent considered the material "Natural".
3. Ranked ordering task: Respondents were asked to order the materials from most natural to least natural, by writing the sample number in labelled positions (labelled 1 to 22).

4. Demographics: respondents were asked a brief set of demographic questions including age and sex.

The original questionnaire for this study was composed in Norwegian and translated to English and Finnish using the following procedure:

1. Translate from Norwegian to English
2. Translate from English to Norwegian to confirm translation
3. Translate from English to Finnish
4. Translate from Finnish to English to confirm translation
5. Translate from English to Slovenian
6. Translate from Slovenian to English to confirm translation

Sample and data collection

The survey was conducted at four locations: Oslo, Norway; Espoo, Finland; Ljubljana, Slovenia; and Koper, Slovenia. In all locations convenience sampling was used to select participants. The survey was conducted in two locations in Slovenia to assess if two very different regions within the same country might have different perceptions of building material naturalness. Koper is located on Slovenia's coast, in a sub-Mediterranean climate with a heavy cultural influence from Italy, while Ljubljana is located centrally in Slovenia and has a subalpine climate.

The sample in Oslo, Norway included members of a sports club aged 15 and older and was 66 % male. In Espoo, Finland, and Ljubljana, Slovenia the surveys were conducted in indoor common areas at university campuses (Aalto University and the University of Ljubljana, respectively) and the respondents were students, faculty, and staff. In Espoo, Finland 38 % of respondents were female and, overall, they were predominantly 35 years of age or younger. In Ljubljana, respondents were younger than their counterparts; most were 25 years of age or younger; 74 % were female. In Koper, most respondents were 25 years of age or younger and 53 % were female. These results are summarised in Table 2.

Table 2: Respondent demographic summary

			Slovenia			
Age Group	Finland	Norway	Koper	Ljubljana	Combined	Total
15-25	18	32	22	35	57	107
26-35	16	18	12	4	16	50
36-45	2	4	5	2	7	13
46 +	3	2	1	-	1	6

No Response	3	-	3	5	8	11
Sex						
Female	16	37	23	34	57	110
Male	24	19	17	9	26	69
No Response	2	-	3	3	6	8
Total Responses	42	56	43	45	88	186

In all locations, building material specimens were arranged on the edge of a table with ample surrounding space for respondents to walk around as they assessed the materials. Specimens were arranged in numerical order around the table to help respondents keep track of which samples they had assessed.

Respondents were asked to only assess the samples visually, and were specifically asked not to touch them. The paperboard boxes each sample was presented in limited the specimens to a top view only. This was intentional to mask the sides of the materials that would have more easily revealed their composite nature in some cases (for example, the wood plastic composite with an imitated wood grain).

Data analysis

Completed paper questionnaires were manually transcribed and imported to the statistical computing program R (R Core Team 2017) for further processing and analysis. In R, the packages ggplot2 (Wickham 2009) and plyr were used to analyse, manipulate, and visualise the data.

The response data for each question were as follows:

1. Natural vs. not natural binary decision task. When natural was selected, ‘1’ was recorded; ‘0’ was recorded when not natural was selected.
2. Scaled rating task. These were recorded directly from the seven-point scale, where 1 indicated not natural and 7 indicated natural.
3. Ranking task. These were recorded as the indicated ordinal rank of each specimen (1 through 22, with 1 indicating the most natural specimen).

The number of responses considered in analysis of each question varied. For the binary decision task and scaled rating responses, respondents occasionally entered two responses for a single specimen, or skipped a specimen altogether. Only complete responses to the ranking task were used; far fewer respondents completed this task completely than the other tasks (Table 3).

Table 3: Number of useable responses from each location for the binary decision task and the scaled rating task.

	Binary decision task (question 1)						Scaled rating task (question 2)					
				Slovenia						Slovenia		
Specimen	Combined	Finland	Norway	Koper	Ljubljana	Combined	Combined	Finland	Norway	Koper	Ljubljana	Combined
OSB	183	41	55	43	44	87	185	41	56	43	45	88
Knotty pine, planed	184	41	55	43	45	88	183	41	55	43	44	87
Particleboard	183	41	55	43	44	87	182	41	55	42	44	86
Cork	183	41	55	43	44	87	183	42	55	43	43	86
Painted MDF (white)	182	41	55	43	43	86	183	42	54	43	44	87
Brick tile	184	41	56	43	44	87	184	42	55	42	45	87
Ceramic tile, white	184	41	56	42	45	87	185	42	55	43	45	88
Woven fabric	183	40	56	43	44	87	184	42	55	43	44	87
WPC, growth rings	184	40	56	43	45	88	182	42	55	40	45	85
Clear pine, rough sawn	184	41	56	42	45	87	185	42	55	43	45	88
MDF, growth rings, white	184	41	56	42	45	87	185	42	55	43	45	88
Clear pine, planed	184	41	56	43	44	87	185	42	55	43	45	88
Steel, milled surface	183	41	56	41	45	86	185	42	55	43	45	88
Woven wool fabric	185	41	56	43	45	88	184	42	55	43	44	87
Stone tile, untreated	185	41	56	43	45	88	182	41	54	43	44	87
Painted planed pine (white)	183	41	56	42	44	86	184	42	54	43	45	88
Ash, HW, untreated	184	41	56	42	45	87	184	42	55	42	45	87
Plastic, polished	185	41	56	43	45	88	184	42	54	43	45	88
MDF, untreated	183	41	56	42	44	87	182	42	54	41	45	86
Steel, painted white	184	41	55	43	45	88	184	42	55	43	44	87
Wallpaper, white	185	41	56	43	45	88	185	42	55	43	45	87
Leather, untreated	182	38	56	43	45	88	184	41	55	43	45	87

The number of responses used in analysis for each specimen is provided in Table 4 for the binary decision task and the scaled rating task.

Table 4: Number of complete responses to the ranking task (question 3) by location.

Location	*n*
Finland, Espoo	32
Norway, Oslo	17
Slovenia	
Koper	33
Ljubljana	29
Combined	62
Total	111

The responses to the binary decision task responses were analysed only with summary statistics. The total number of respondents per specimen and fraction of respondents considering the material natural are reported for each location group, including the combined total for all locations.

The responses to the category scaling task were compared using pairwise Wilcoxon rank sum tests with Bonferroni adjustments for multiple comparisons. Estimated mean ratings with 95 % confidence intervals were calculated for each country group and are reported and graphically displayed. In the case of the stone tile specimen (number 510) rating for all respondents, the calculated 95 % CI exceeded the maximum rating (seven). In this case, the 95 % CI was bounded at the maximum rating limit for display and reporting.

Responses to the ranking task were analysed with two rank correlation coefficients, Spearmen's ρ and Kendall's τ. Spearman's rank correlation coefficient (ρ) compares the sum of the squared differences in ranking between groups (i.e., locations in this study). This value is then normalised between -1 and 1. Kendall's τ is fundamentally different, in that it does not directly compare the difference between any two rankings. This coefficient compares the number of concordant and discordant pairs then normalises between -1 and 1. In both cases, a rank coefficient of positive 1 describes perfect correlation, and negative 1 describes perfectly uncorrelated rankings.

3.3 Human stress and stress recovery in office-like environments

3.3.1 Materials

The materials used for the human stress and stress recovery experiment included: the test environments and the furniture in them; heart rate monitors; a standard mood assessment scale; short films used as stressors; reading materials a performance task; collection devices used to collect the saliva samples the analyses is based on; and the processing materials and equipment used to calculate cortisol concentrations in the saliva samples.

Test environments

The test environments were two offices (A and B) at the University of Primorska Livade 1.0 building in Izola, Slovenia. The offices were divided into two equal sized portions, approximately 2.5 m × 2.5 m resulting in a total of four test environments. The test environments in each divided office were isolated with natural tone curtains that blocked exterior windows in the office to reduce the impact of daylighting, weather, and the time of day testing took place. The two test environments in each office were a control environment with white furniture with no visible wood surface and a wood environment with wood furniture. The test environments were:

1. Divided office A: Oak furniture (Office A:Oak).
2. Divided office A: Control furniture (Office A:Control).
3. Divided office B: Walnut furniture (Office B:Walnut).
4. Divided office B: Control furniture (Office B:Control).

The white furniture used in the control environment of each divided office was identical (Figure 3).

Figure 3: Control environment furniture.

One wood environment used oak veneered furniture (Office A:Oak, Figure 4), and the other used American walnut veneered furniture (Office B:Walnut, Figure 5).

Figure 4: Oak furniture in Office A:Oak.

Figure 5: Walnut furniture in Office B:Walnut.

Each divided office contained a control room to allow testing subjects each half of the divided office and to minimise any variation related to potential uncontrollable differences present in each room. In each environment, the furniture included a desk, a bookshelf above the desk, a desk-height filing cabinet immediately next to the desk, and a set of drawers that fit under the desk (Figure 6).

Figure 6: Test environment with visible components including shelving, desk, drawers, filing cabinet, and wall cover. This example depicts oak furniture.

The wood species selected present different attributes of wood including colour and grain pattern. The oak furniture was light in colour and had a visible grain pattern, while the walnut was darker and but grain patterns were still visible (Figure 7, Figure 8). Although lighting was kept at the same levels in each test room, the combination of room position and material properties caused the luminance levels to be different in each of the test rooms (Table 5: Luminance levels in each test environment (range is minimum and maximum value over 20 second period).).

Figure 7: Surface detail, oak furniture.

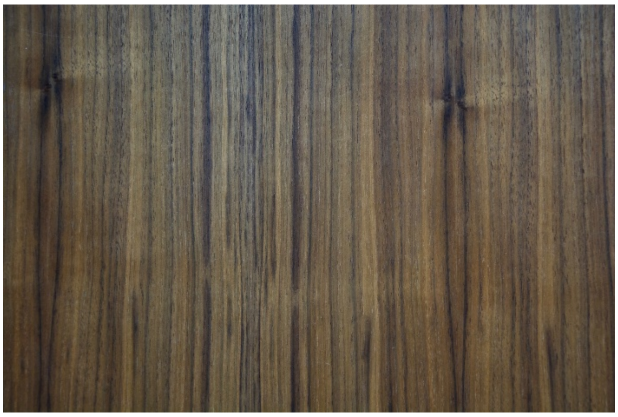


Figure 8: Surface detail, walnut furniture.

Table 5: Luminance levels in each test environment (range is minimum and maximum value over 20 second period).

Test environment	Luminance (lux)
A:Control	833 to 837
A:Oak	372 to 374
B:Control	442 to 446
B:Walnut	580 to 586

Saliva collection and immunoassay kits

Saliva was collected at seven points during each test (14 total for each subject). Saliva samples were collected using Salivette® Cortisol, code blue collection devices (Sarstedt, Germany). Subjects were instructed to chew the swab for 45 seconds, and were timed to make sure enough saliva was collected for processing. These devices consist of a two-chambered device with a cap, and a chewable, biocompatible synthetic swab. Prior to testing, each Salivette® was labelled with a subject identifier, a test identifier, and a sample identifier. For example, the collection device for the third saliva sample during subject 99's second test would be labelled a pseudonym constructed: "P099-2-3".

Following collection, saliva samples were immediately frozen for later processing.

Saliva samples were processed using enzyme-linked immunoabsorbant assay (ELISA) kits designed specifically for salivary cortisol assessment (Diametra, Italy). All kits were from the same lot (#4487B). Each kit contains the requisite materials, apart from disposable pipette tips. The materials included in the kit were:

- 1 96-well microtitre plate, coated: antibody anti Cortisol adsorbed on the plate
- Calibrators, seven vials (with known cortisol concentrations)
    - Calibrator concentrations were: 0, 0.138, 1.38, 2.76, 13.80, 27.60, 55.20, 276.0 nmol/L
- Incubation buffer (phosphate buffer 50 mmol, Bovine Serum Albumin (BSA) 1 g/L)
- Conjugate (horseradish peroxidase, HRP)
- TMB substrate (H_2O_2-3,3',5,5'-tretramethylbenzidine, 0.26 g/L)
- Stop solution (sulphuric acid, H_2SO_4, 0.15 mol/L)
- Concentrated wash solution (10x concentration, phosphate buffer 0.2M)
- Within-kit controls at two cortisol concentrations

External cortisol controls at three concentrations were also attained (Diametra, Italy).

The equipment used to process the ELISA kits were:

- Centrifuge (capable of 1000g at room temperature)
- Rotating mixer
- Incubation oven (set to 37 ºC)
- Pipettes, and pipette tips
- Pipetting robot
- Blank microtitre plates
- Microplate reader (capable of reading at 450 nm, and 620 nm to 630 nm)
- Lab safety equipment (gloves, coats, glasses)

WHO-5 well-being index

The WHO-5 well-being index is a short questionnaire to assess respondent well-being. The questionnaire is self-reported and provides subjective values (World Health Organisation 1998; Topp et al. 2015). It consists of five non-invasive questions with responses provided on a five-point scale. The purpose of using this questionnaire in this study was to determine if there were any major changes in subjective well-being that may influence the outcome between the first and second tests. The WHO-5 questionnaire was available to subjects in either English or Slovenian (see Attachment 5 WHO-5 Well-being questionnaire in English). The Slovene and English versions, along with many other languages, are made freely available by the Psykiatric Center North Zealand (Denmark).

Heart rate monitoring

Heart rate was monitored using a Garmin F920 sports watch connected to a chest band worn on the skin. Heart rates are recorded on the watch, then can be transferred to a computer and analysed later.

Inducing stress

Stress was induced using an emotion induction procedure by presenting film segments to elicit a negative affective state (cf. Dickerson and Kemeny 2004). Two segments of feature films were selected and used to induce stress with the presumption of fair use of copyrighted materials (Soderbergh 2012; Greengrass 2016). Each video was approximately 6 minutes long, and contained similar, but not identical content. Both were excerpts from separate action films featuring intense scenes of physical violence. Videos were shown on a tablet or laptop computer, with the volume on. The device was left in the test environment until the following saliva sample collection. Video selection was randomised between tests, and subjects did not see the same video twice.

Performance task

The proofreading task, meant to provide a means to measure productivity, was performed on published texts, each split into two parts. A Slovenian text and English text were selected for this purpose. The Slovenian language text was "Črni Mož", as published in *Amerikanski Slovenec* in 1934 (*Amerikanski Slovenec* 1934). The English language text was the long form *New Yorker* article, "How to be good" (MacFarquhar 2011). In both cases, minor spelling, typographical, and grammatical errors were introduced to the texts at a rate of 3 to 10 per page. Each text was divided into multiple parts with a minimum length of 5,500 words. This task was expected to take longer than the remaining test time to complete, and participants were not expected to finish.

3.3.2 Methods

In this experiment, human subjects were tested to determine if their stress response, recovery, and overall stress level varied between office-like environments with wood furniture and with non-wood furniture.

Experimental design and procedure

In this within-subjects experiment, each subject was tested twice; once in the control environment and once in a wood environment of the same divided office (for example, both A:Oak and A:Control). The order of tests was randomised (i.e., assignment to wood-first, or control-first). The tests were conducted at the same time of day to avoid any differences that may have occurred due to the circadian rhythm of cortisol release. Tests were conducted approximately 5 to 10 days apart based on subject availability. During each test, the procedure had two phases: preparation and experiment.

In the preparation phase, the following steps were taken:

1. Subjects were directed to their assigned test environment (control or wood), and asked to make themselves comfortable in the desk chair. Subjects were allowed to adjust the chair height and other settings to their preference.
2. Subjects were presented with the informed consent document. They were asked to read it, ask any questions, and voice any concerns. If satisfied with the test procedure and still willing to participate, they were asked to sign the informed consent document. It was then counter signed by the researcher, and archived.
3. Subjects were asked to complete the WHO-5 well-being index questionnaire.
4. Subjects wore the chest band used to monitor heart rate. Verification that readings were being made took place. This completed the preparation phase of the test.

During the experiment phase, the following steps were taken:

1. Subjects were given a Salivette® saliva collection device, instructed on its use, and asked to begin gently chewing the swab.
    a. A timer was started when the subjects placed the swab in their mouth.
2. Following the first saliva collection, subjects were allowed to acclimate to the test environment for 15 minutes.
3. At minute 15, subjects provided the second saliva sample.
4. Directly after collecting the second saliva sample, the researcher began the six-minute video that served as a stressor.
5. At minute 25, the third saliva sample was collected and the video device was removed from the room.

6. At minute 35, the fourth saliva sample was collected.
7. At minute 45, the fifth saliva sample was collected and subjects were given the proofreading text and a writing instrument. Instructions for this process were reiterated.
8. At minute 60, the sixth saliva sample was collected.
9. At minute 75, the seventh, and final saliva sample was collected. The timer and heart rate recording were stopped. The proofreading text was collected and stored for later analysis.

Following completion of the test, subjects were asked to remove the heart rate monitor, which was then cleaned for the next subject.

The informed consent document was based on the World Health Organisation informed consent template for clinical studies, but modified for this experiment. It was available in Slovenian and English (see Attachment 6 Informed consent form in English). The translation from English to Slovene was prepared at the University of Primorska.

Sampling and demographics

Subjects were recruited through e-mail distributed to regional organisations and mailing lists, through advertisements on local media, and through social networks. Additional recruiting took place in classrooms on campus at the University of Primorska.

Restrictions on the sample included:

- Minimum age: 18
- Non-smokers only
- Healthy subjects not taking prednisolone (a corticosteroid treatment that interferes with salivary cortisol analysis), without heart conditions exacerbated by stress, and without other stress related conditions
- Female or male

In addition to the sample restrictions, subjects were also asked about any hormone therapy they were undergoing (including contraceptives), and hormone-related conditions.

The resulting sample was 61 healthy adults, aged 18 and older from Slovenia and Italy, including long-term visitors to Slovenia (e.g., foreign students, visiting professors). Subjects were between 18 and 52 (mean: 27.7 ± 9.3 years); 47 were female, 14 were male. 50 participants selected the Slovenian language text, while 11 selected the English language text. Of those 11, three spoke English as a second language. 33 subjects were undergraduate or Master's students and 28 were Ph.D. students or professionals.

Six subjects used chemical contraceptives and one had a hormone condition which required treatment with hormone supplements. None of these cases produced unexpected or peculiar results.

Cortisol concentration determination

To process the saliva samples the following procedure, based on ELISA kit manufacturer suggestions, was followed. The steps were:

1. Remove samples from the freezer and allow to thaw at room temperature
2. Centrifuge saliva samples at 1000g at 21 ºC
3. Remove and discard swab and swab insert
4. Place calibrators and controls on a rotating mixer and let run for at least 5 minutes at approximately 250 rpm
5. Pipette 100 µL saliva from each Salivette® to an intermediary microtitre plate, replacing the pipette tip after each saliva sample to avoid contamination
6. Prepare diluted conjugate, according to kit instructions
7. Transfer intermediary plate to the pipetting robot, run the programme to distribute samples from the intermediary plate to the treated mictrotitre plate
8. Transfer the diluted conjugate to the treated tray using the pipetting robot, leaving two blanks
9. Cover tray in foil and incubate at 37 ºC for 60 minutes in the laboratory oven
10. Prepare diluted wash solution
11. Remove tray from oven, remove tray contents (shake in to the sink)
12. Wash tray wells three times with the diluted wash solution
    a. Use multi-channel pipette to transfer 300 µL to each well (100 µL 3 times)
    b. Shake the plate contents into the sink, tapping it dry thoroughly
    c. Repeat steps a and b 2 more times
13. Add 100 µL TMB substrate to each well using the pipetting robot, leaving two negatives (spaces with no saliva, and no TMB Substrate, but all other components)
14. Cover and incubate at room temperature for 15 minutes
15. Add 100 µL of stop solution to each well using the pipetting robot
16. Read the optical density from the microplate reading at 450nm against reference readings at 620 nm or 630 nm.
17. Save the output file for later processing.

Following this process saliva samples were refrozen and stored for later processing, if necessary.

Each test produced 7 saliva samples (854 total saliva samples). Each saliva sample was tested in duplicate, require a total of 1708 free microtitre plate wells. Each 96-well microtitre plate had 70 free wells after calibrators, blanks, negatives, and controls. This provided space for 5 tests to be assayed fully on each plate (7 samples per test, in duplicate, required 14 wells). An example of typical tray layout is presented in **Error! Reference source not found.**, where saliva samples are indicated with a string beginning with a letter from A to E to differentiate each set, a numeric to indicate the time within the test the sample was collected (i.e., 1 for the initial sample, 7 for the final sample), then a dash followed by another numeric indicator to identifying which duplicate is indicated (1 or 2). For example, A7-2 indicates the second duplicate of the 7th (final) sample for person A and E3-1 indicates the first duplicate of the third sample (minute 25) for person E.

C0-1	C0-2	CL-1	A1-1	A1-2	B1-1	B1-2	C1-1	C1-2	D1-1	D1-2	E1-1
C1-1	C1-2	CL-2	A2-1	A2-2	B2-1	B2-2	C2-1	C2-2	D2-1	D2-2	E2-1
C2-1	C2-2	CM-1	A3-1	A3-2	B3-1	B3-2	C3-1	C3-2	D3-1	D3-2	E3-1
C3-1	C3-2	CM-2	A4-1	A4-2	B4-1	B4-2	C4-1	C4-2	D4-1	D4-2	E4-1
C4-1	C4-2	CH-1	A5-1	A5-2	B5-1	B5-2	C5-1	C5-2	D5-1	D5-2	E5-1
C5-1	C5-2	CH-2	A6-1	A6-2	B6-1	B6-2	C6-1	C6-2	D6-1	D6-2	E6-1
C6-1	C6-2	Neg	A7-1	A7-2	B7-1	B7-2	C7-1	C7-2	D7-1	D7-2	E7-1
B	B	Neg	E1-2	E2-2	E3-2	E4-2	E5-2	E6-2	E7-2	Con-A	Con-B

Figure 9: Example microtitre plate layout. C0-C6 are calibrators, CL, CM, CH are external controls, Con-A and Con-B are internal controls, B is blank, Neg is negative. Wells labelled A1 through E7 are the first through seventh samples from tests A through E. "-1" and "-2" are the original and duplicate positions, respectively.

In addition to the saliva samples tested on the microtitre plate, the other wells included:

1. Seven calibrators with different known cortisol concentrations, in duplicate (C0-1 through C6-1 and C0-2 through C6-2 in **Error! Reference source not found.**) used for curve fitting.

Table 6: Calibrator labels and cortisol concentrations.

Calibrator	Known cortisol concentration (nmol/L)
Calibrator 0 (C0)	0
Calibrator 1 (C1)	1.38
Calibrator 2 (C2)	2.76
Calibrator 3 (C3)	13.80
Calibrator 4 (C4)	27.60
Calibrator 5 (C5)	55.20

Calibrator 6 (C6)	276.00

2. External controls with three different cortisol concentration ranges, in duplicate (CL1, CL2, CM1, CM2, CH1, CH2 in Figure 9**Error! Reference source not found.**). Used to verify dose-response curves return values within an acceptable range. The same set of external controls were used across all plates.

Table 7: External controls used for verification of dose-response curve fit with expected ranges.

External Control	Expected concentration range (nmol/L)
Control Low (CL)	1.57 to 3.95
Control Medium (CM)	45.6 to 92.7
Control High (CH)	88.6 to 117

3. Internal controls with two different cortisol concentrations, not duplicated (Con-A, Con-B in Figure 9**Error! Reference source not found.**). Used to verify dose-response curves return values within an acceptable range. Internal controls were specific to each kit and used only on the associated plate.

Table 8: Internal controls used for verification of dose-response curve fit with expected ranges.

Internal Control	Expected concentration range (nmol/L)
Control Low (Con-A)	3.31 to 7.40
Control High (Con-B)	18.4 to 35.5

4. Blanks (B in Figure 9**Error! Reference source not found.**). Wells left blank throughout the entire procedure. Used to verify reading accuracy and to compare with Negatives (values should match). Blanks are also useful for diagnosis of procedural errors that may have occurred during the assay.
5. Negatives (Neg in Figure 9**Error! Reference source not found.**). Negatives received all additives apart from cortisol or saliva and the TMB substrate. Used to verify reading accuracy and to compare to negatives (values should match). Negatives are also useful for diagnosis of procedural errors that may have occurred during the assay

In total, 25 microtitre plates were used in this analysis. On the final plate, space remained for three samples to be tested a second time, providing an opportunity to compare readings between plates for the same saliva samples.

In one case (plate 23), the pipetting robot failed to securely attach a pipette tip to one pipette channel, leaving the second row on the plate without TMB substrate, producing negative readings for the entire row.

In another case (plate 6), a power outage in the building occurred while the pipetting robot was transferring the diluted conjugate to the plate. This event required that the diluted conjugate was manually transferred to columns six through 12.

Cortisol analysis

Optical densities from microtitire plate readings taken at 450 nm were converted to cortisol concentrations by first fitting a curve to the mean value of each calibration duplicate (C0 through C6 in Figure 9**Error! Reference source not found.**). The curve was fit using a 4-parameter log-logistic regression as suggested by the ELISA Cortisol kit manufacturer (i.e., the dose-response model function in Eq. 1). Following curve fitting, cortisol concentrations were calculated for controls and saliva samples.

$$f\big(x,(b,c,d,e)\big) = c + \frac{d-c}{(1+exp^{(b(\log(x)\,-\,\log(e))})} \qquad \text{Eq. 1}$$

Where,

x =	optical density reading
b =	steepness of the curve
c =	lower asymptote
d =	upper asymptote
e =	midpoint between asymptotes
exp =	exponent
log =	natural logarithm

Cortisol concentrations were compared within-subjects, meaning that the compared value was the difference between an individual's cortisol concentration in the wood environment and control environment.

Cortisol concentration was compared within-subjects in four different scenarios corresponding to the three hypotheses:

1. The overall mean cortisol concentration throughout the test duration (hypothesis 1).

2. The mean cortisol concentration during the acclimation period (minutes 0, 15, and 25) (hypothesis 1).
3. The mean cortisol concentration during the response period, which included four samples collected at the 35th, 45th, 60th, and 75th minute. This period is when salivary cortisol concentrations were expected to change in response to the stressor presented at minute 15 (hypothesis 2).
4. The apparent degree of recovery as indicated by the difference between the maximum cortisol concentration during and test period and the minimum cortisol concentration observed after the maximum (hypothesis 3).

Within-subject comparisons between environment conditions were made using the 1-sided, paired Wilcoxon signed rank test because the data did not meet the assumptions of the Student's t-test of equal variance and normally distributed data. The 1-sided test was used because the hypotheses state the cortisol concentrations would be greater in each control environment when compared to the corresponding (within-subject) wood environment. Accordingly, the 1-sided test was parameterised to detect higher cortisol concentrations in the control room for hypotheses (i.e., alternative hypothesis was that the cortisol concentration in the control room was greater than in the wood rooms). 1-sided tests provide greater power in detecting differences (i.e., can detect smaller differences) than their 2-sided counterparts, but are limited to detecting differences only when one value is expected greater (or lower) than the value it is compared to. The exception to this is the comparison of recovery, where the degree of recovery (the difference between the maximum cortisol concentration observed during the response period and the final cortisol concentration) was expected to be greater in the wood room than in the corresponding (within-subjects) control environment.

Heart rate monitoring

Heart rates were converted from the propriety XML format (TCX) output by the Garmin software tools to comma separated values in a text file using R (R Core Team 2017) and a modified version of an open-source R-script (White and Kleinböhl 2013). In many instances, gaps in the heart rate record were found. Typically, this was caused by the band contacts not maintaining connections, and in some cases batteries running out of power. In a few instances, readings could not be acquired at all due to chest bands not fitting, or failing to supply readings.

WHO5 well-being index

Responses to the WHO5 well-being index were manually transcribed from the paper questionnaire to a digital format for analysis. Scores for this test are the sum of the number value for each response, multiplied by four to place the index on a scale of 0 to 100.

Ethics approval for testing human subjects and anonymity

Medical ethics approval for this experiment was required because it dealt with human subjects. An application was prepared and submitted to the Komisija Republike Slovenije za medicinsko etiko on 6 November, 2014 (Attachment 7 KMERS application). Approval was received granted 16 December, 2014; the reference number is 78/12/14 (Attachment 8 KMERS approval).

Participant identities are masked with pseudonyms to ensure their anonymity in this report. These were created by assigning a string composed of three randomly selected capitalised alpha characters (A to Z) followed by two randomly selected digits. During the experiment anonymity was provided with by separating real names and contact information from experimental data. This information was linked with the pseudonym.

Data analysis

Analysis was conducted in R 3.4.1 (R Core Team 2017) using RStudio 1.0.153 (RStudio Inc. 2017). Charts were made using the R packages ggplot2 (Wickham 2009) and ggforce (Pedersen 2016). Dose-response curves were fit using the R package drc (Ritz et al. 2015). Documentation of the analysis in R is included as an attachment (Attachment 9 Stress Data processing and analysis in R).

Within-subject comparisons of responses to the different stressors (videos) were made using the 1-sided, paired, Wilcoxon signed rank test because the data did not meet the assumptions of a t-test based on the normal distribution and equal variance. Within-subject comparisons of the WHO-5 well-being index differences between tests were made using the 2-sided, paired Student's t-test.

The raw data for this study were the transmittance readings for each well on the microtitre plates, subject heart rate during each test, and demographic data. Demographic data consisted of age in years, sex, and occupation category (student or professional). Heart rate was recorded as beats per minute at 1 second intervals throughout the test duration. Microtitre plate readings were optical densities taken at 450 nm then converted to cortisol concentrations in nmol/L. WHO-5 responses were numerical values between 0 and 100.

4 RESULTS

The results of the naturalness study and the human stress in the built environment study are detailed here. In each experiment, the findings of the literature review (Burnard and Kutnar 2015) were expanded through new research efforts to better understand how building material naturalness, particularly wood products, are perceived by users and how using those materials influences human reactions to stress and recovery from stress.

The results of the building material naturalness study demonstrate respondents from all countries find wood that has undergone the least transformation to be most natural, followed by stone, in each country surveyed. Materials having undergone greater degrees of transformation were considered less natural in each country as well. Slovenian respondents differed from their counterparts in Finland and Norway in their recognition of imitated wood (WPC with imitated growth rings); in Slovenia respondents characterised this material as more natural than those in Finland and Norway. These results were published in Burnard et al. (2017).

The results of the human stress in the built indoor environment study indicated that under certain conditions, using wood in the built indoor environment may lead to improved stress responses. For example, stress responses indicated by salivary cortisol levels were lower in the test environment with oak furniture (Office A: oak) than in the corresponding control environment (Office A: control). The reduced reaction to stress has a small effect for any single stressful situation, but overtime, even small reductions to stress responses can contribute to improve mental and physical health outcomes, which in turn lead to improved social outcomes (McEwen 1998).

4.1 Building material naturalness

Respondents in Slovenia, Finland, and Norway consistently determined materials which had undergone less apparent transformation to be natural in the binary decision task. Likewise, respondents from all locations consistently rated and ranked these materials as more natural than their counterparts which had undergone more transformative processes.

4.1.1 Binary decision task responses

Responses to the binary decision task indicated that the pine specimens were the most consistently rated as natural (Table 9, Table 10, Table 11, Figure 10). The planed, pine specimen with knots was considered natural more consistently than any other specimen; 100 % of respondents in Finland and Norway marked it as natural and 96.6 % of respondents from Slovenia marked it as natural (Table 11). All untreated wood specimens, along with the stone tile specimen, were considered natural by more than 88 % of all respondents. The most significant divergences in rates were particleboard, untreated medium density fibreboard (MDF), and the wood plastic composite specimen with imitated growth rings. Only 29.3 % of respondents in Finland considered the particleboard specimen to be natural. In Norway, 69.8 % of respondents considered the particleboard specimen to be natural, and 62.1 % of the Slovenian respondents considered it natural (54.5 % and 50.9 % in Koper and Ljubljana, respectively). Fewer than 20 % of respondents in Finland found the untreated MDF specimen to be natural, while more than 50 % of respondents in other locations considered it to be natural. The WPC specimen with imitated growth rings was considered natural in fewer than 25 % of the responses from Finland and Norway, while in Slovenia this specimen was considered natural by nearly 50 % of the respondents (51.2 % from Koper and 46.7 % from Ljubljana).

Table 9: Combined results for the binary decision task, all locations.

	All locations	
Specimen	Natural (%)	n
Knotty pine, planed	98.3	184
Clear pine, rough sawn	97.0	184
Clear pine, planed	92.7	184
Stone tile, untreated	89.2	185
Ash, HW, untreated	88.0	184
OSB	76.1	184
Brick tile	75.7	183
Cork	54.5	183
MDF, growth rings, white	53.6	183
Particleboard	51.1	185
MDF, untreated	44.3	184
Woven wool fabric	41.6	183
Painted planed pine (white)	37.2	183
Leather, untreated	37.1	184
WPC, growth rings	36.5	182
Painted MDF (white)	27.3	185
Wallpaper, white	26.9	182
Ceramic tile, white	13.6	184
Steel, milled surface	9.2	183
Woven fabric	9.2	183
Plastic, polished	7.7	184
Steel, painted white	6.1	185

Table 10: Binary decision task responses for Koper and Ljubljana Slovenia.

Specimen	Koper, Slovenia Natural (%)	n	Ljubljana, Slovenia Natural (%)	n
Knotty pine, planed	97.7	43	95.6	45
Clear pine, rough sawn	92.9	42	97.8	45
Clear pine, planed	86.0	43	90.9	44
Stone tile, untreated	81.4	43	88.9	45
Ash, HW, untreated	85.7	42	91.1	45
OSB	79.1	43	79.5	44
Brick tile	69.8	43	81.8	44
Cork	51.2	43	56.8	44
MDF, growth rings, white	54.8	42	53.3	45
Particleboard	69.8	43	54.5	44
MDF, untreated	50.0	42	52.3	44
Woven wool fabric	39.5	43	48.9	45
Painted planed pine (white)	31.0	42	38.6	44
Leather, untreated	39.5	43	31.1	45
WPC, growth rings	51.2	43	46.7	45
Painted MDF (white)	41.9	43	23.3	43
Wallpaper, white	27.9	43	35.6	45
Ceramic tile, white	11.9	42	15.6	45
Steel, milled surface	7.3	41	4.4	45
Woven fabric	11.6	43	11.4	44
Plastic, polished	9.3	43	4.4	45
Steel, painted white	16.3	43	13.3	45

Table 11: Binary decision task responses for Slovenia, Finland, and Norway.

Specimen	Slovenia Natural (%)	n	Finland Natural (%)	n	Norway Natural (%)	n
Knotty pine, planed	96.6	88	100	41	100	55
Clear pine, rough sawn	95.4	87	97.6	41	100	56
Clear pine, planed	88.5	87	97.6	41	96.4	56
Stone tile, untreated	85.2	88	90.2	41	96.4	56
Ash, HW, untreated	88.5	87	87.8	41	87.5	56
OSB	79.3	87	65.9	41	80	55

Brick tile	75.9	87	78.0	41	73.2	56
Cork	54.0	87	46.3	41	63.6	55
MDF, growth rings, white	54.0	87	63.4	41	42.9	56
Particleboard	62.1	87	29.3	41	50.9	55
MDF, untreated	51.2	86	19.5	41	55.4	56
Woven wool fabric	44.3	88	31.7	41	46.4	56
Painted planed pine (white)	34.9	86	29.3	41	50	56
Leather, untreated	35.2	88	47.4	38	30.4	56
WPC, growth rings	48.9	88	25.0	40	23.2	56
Painted MDF (white)	32.6	86	17.1	41	25.5	55
Wallpaper, white	31.8	88	17.1	41	28.6	56
Ceramic tile, white	13.8	87	7.3	41	19.6	56
Steel, milled surface	5.8	86	7.3	41	5.4	56
Woven fabric	11.5	87	5.0	40	8.9	56
Plastic, polished	6.8	88	9.8	41	7.1	56
Steel, painted white	14.8	88	7.3	41	0	55

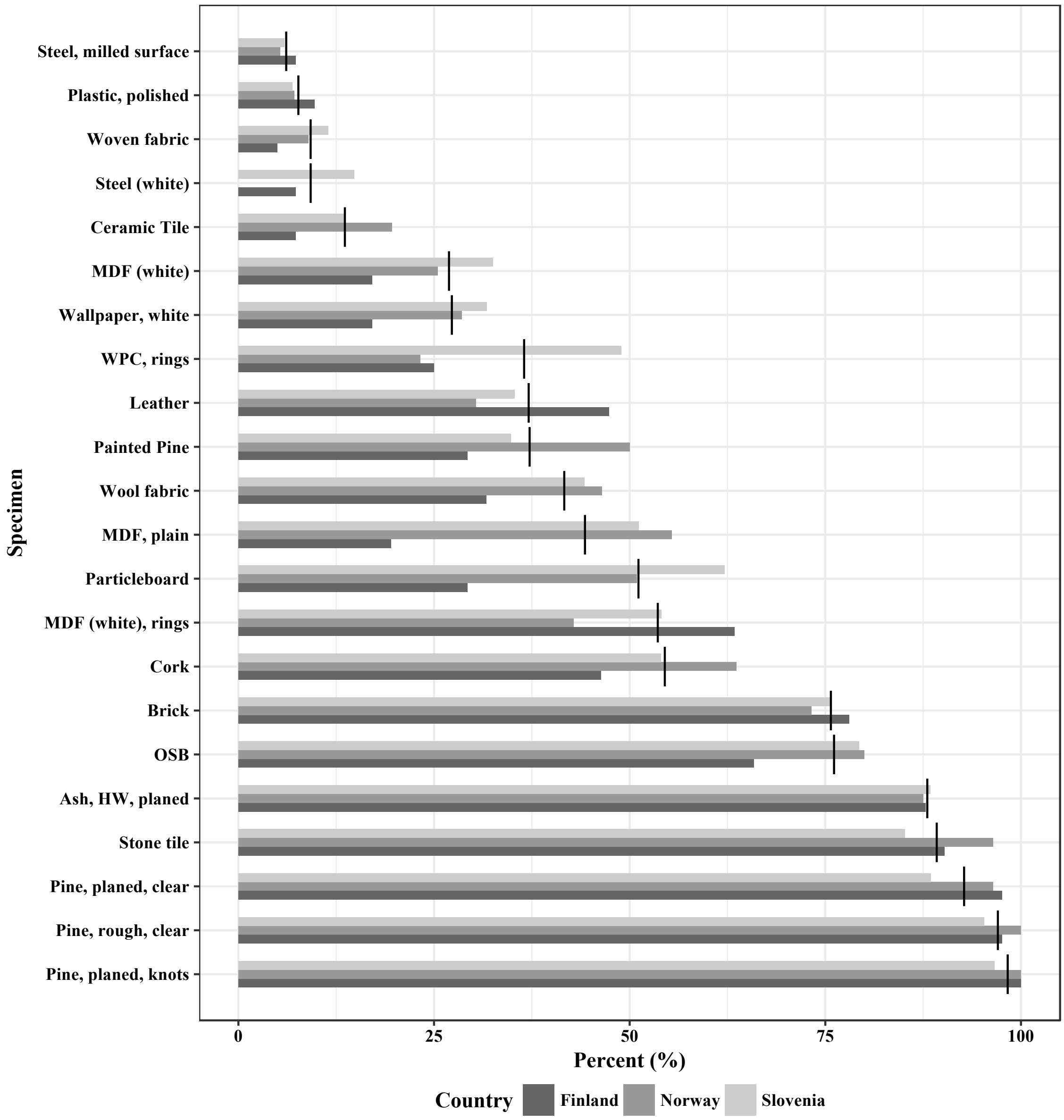


Figure 10: Binary response results for Finland, Norway, and Slovenia. Bars indicate the percent of respondents identifying the specimen as natural from each country, the vertical line indicates the mean percent for all countries.

4.1.2 Building material naturalness ratings

The results of the rating task were well-aligned with the binomial decision task. In general, there was agreement between respondents and the solid wood and stone tile specimens were rated as the most natural (

Table 12, Figure 11).

Table 12 Overall combined naturalness ratings and 95 % Bonferroni adjusted confidence intervals.

Specimen	Mean	95 % CI
Clear pine, rough sawn	6.40	6.22-6.58
Knotty pine, planed	6.38	6.22-6.54
Clear pine, planed	6.16	5.98-6.34
Stone tile, untreated	6.03	5.80-6.27
Ash, HW, untreated	5.51	5.31-5.70
OSB	5.02	4.81-5.23
Brick tile	4.93	4.67-5.20
MDF, growth rings, white	4.35	4.12-4.58
Cork	4.23	4.02-4.45
Particleboard	4.13	3.92-4.33
Painted planed pine (white)	3.86	3.66-4.06
MDF, untreated	3.72	3.52-3.92
WPC, growth rings	3.64	3.40-3.88
Woven wool fabric	3.55	3.33-3.78
Leather, untreated	3.35	3.09-3.62
Painted MDF (white)	3.15	2.94-3.36
Wallpaper, white	3.01	2.81-3.20
Woven fabric	2.64	2.45-2.83
Ceramic tile, white	2.37	2.15-2.59
Steel, painted white	2.03	1.84-2.21
Plastic, polished	1.92	1.71-2.13
Steel, milled surface	1.89	1.70-2.07

Figure 11: The 5 material specimens rated as the most natural by respondents. From left, and in descending order: rough, clear pine; planed, knotty pine; planed, clear pine; stone tile; planed ash heartwood.

The materials most frequently deemed not natural in the binomial decision task, steel, plastic, ceramic tile, and woven fabric, were rated as the least natural specimens in the rating task (

Table 12, Figure 12).

Figure 12: The five lowest rated building materials in descending order of perceived naturalness. From left: woven fabric, ceramic tile, steel (white), plastic, milled steel.

Country-to-country ratings were generally consistent, with the greatest divergences in naturalness ratings occurring for the material specimens that imitate real wood. The wood plastic composite with imitated growth rings was rated 1.22 scale points more natural in Slovenia than in Norway, and 0.8 scale points more natural in Slovenia than in Finland (Table 13). Particleboard was also rated notably more natural in Slovenia than in Finland, while Brick tile was rated as more natural in Finland than in Slovenia. In Norway, the MDF specimen with imitated growth rings that was painted white was rated lower than in Finland or Slovenia (Norway: 3.89, Finland: 4.69, Slovenia: 4.47; Table 13).

Table 13: Mean naturalness ratings and 95 % Bonferroni adjusted confidence intervals for each country.

	Slovenia		Finland		Norway	
Specimen	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
Clear pine, rough sawn	6.47	5.98-6.96	6.45	6.08-6.82	6.25	5.80-6.70
Knotty pine, planed	6.51	6.06-6.96	6.32	5.97-6.66	6.33	5.92-6.75
Clear pine, planed	6.44	5.94-6.93	5.98	5.60-6.35	6.07	5.62-6.52
Stone tile, untreated	6.35	5.70-7.00	6.12	5.63-6.61	5.72	5.13-6.32
Ash, HW, untreated	5.44	4.88-5.99	5.36	4.94-5.77	5.62	5.11-6.13
OSB	5.00	4.44-5.56	4.59	4.16-5.01	5.24	4.72-5.76
Brick tile	4.95	4.21-5.68	5.45	4.90-6.00	4.62	3.95-5.29
MDF, growth rings, white	3.89	3.28-4.50	4.69	4.23-5.15	4.47	3.90-5.03
Cork	4.29	3.67-4.91	4.00	3.54-4.46	4.31	3.75-4.88
Particleboard	4.16	3.61-4.72	3.49	3.07-3.91	4.41	3.90-4.92
Painted planed pine (white)	4.15	3.60-4.70	3.67	3.26-4.08	3.77	3.27-4.28
MDF, untreated	3.83	3.28-4.39	3.29	2.87-3.70	3.86	3.35-4.37
WPC, growth rings	2.98	2.37-3.59	3.36	2.90-3.82	4.20	3.63-4.77
Woven wool fabric	3.56	2.94-4.18	3.19	2.72-3.66	3.72	3.16-4.29
Leather, untreated	3.20	2.44-3.96	3.63	3.06-4.21	3.32	2.63-4.01
Painted MDF (white)	3.19	2.59-3.78	3.05	2.60-3.49	3.18	2.64-3.73
Wallpaper, white	2.84	2.29-3.39	2.81	2.40-3.22	3.20	2.70-3.71

Woven fabric	2.67	2.15-3.20	2.26	1.87-2.66	2.79	2.31-3.28
Ceramic tile, white	2.38	1.75-3.01	1.98	1.50-2.45	2.50	1.92-3.08
Steel, painted white	1.82	1.30-2.34	1.81	1.42-2.20	2.26	1.79-2.74
Plastic, polished	2.07	1.48-2.67	1.62	1.17-2.07	1.97	1.42-2.51
Steel, milled surface	1.71	1.19-2.23	1.55	1.15-1.94	2.16	1.68-2.64

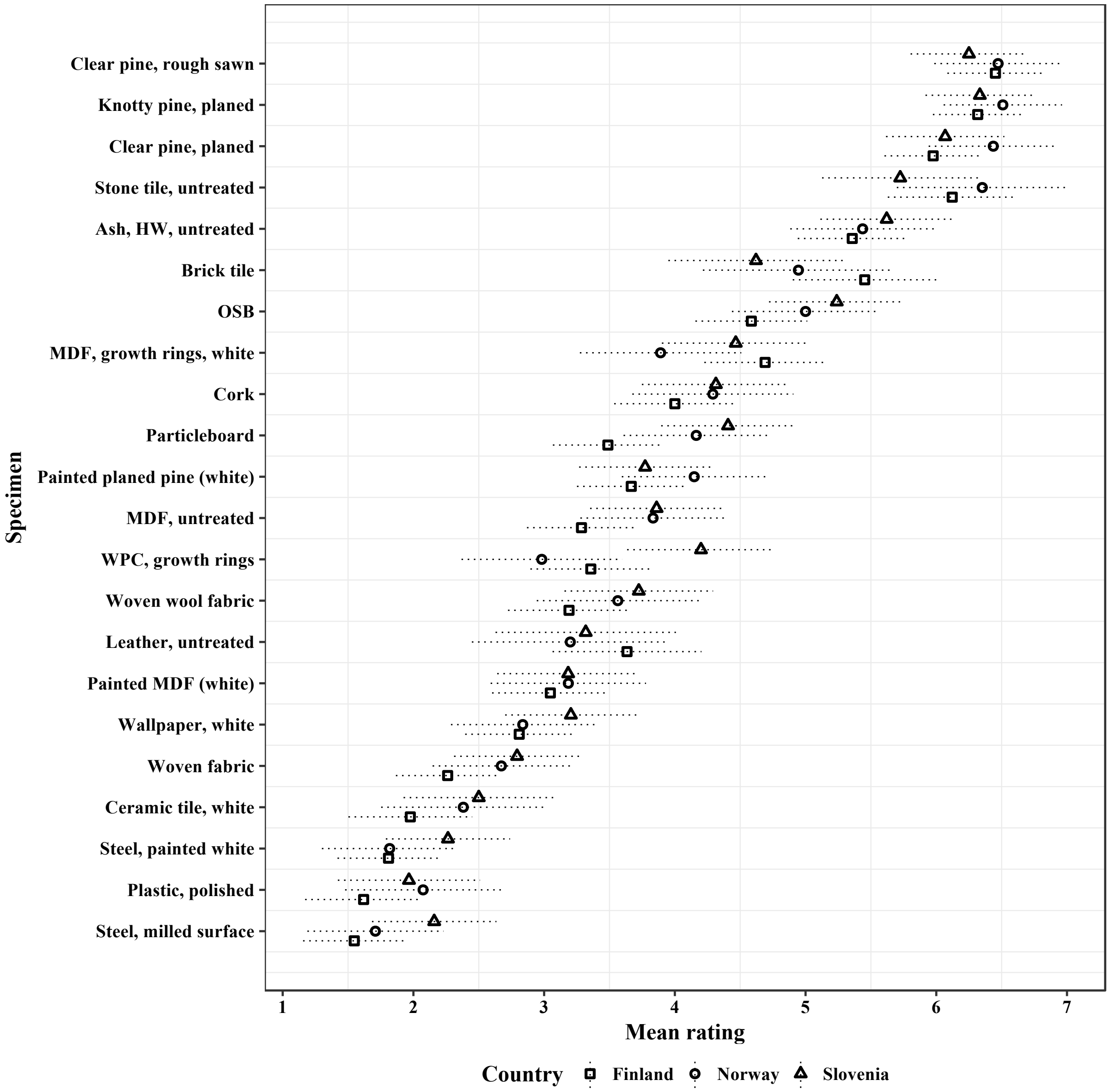


Figure 13: Mean naturalness rating on a seven-point scale, with 95 % Bonferroni-adjusted confidence intervals. Ordered by mean rating for all respondents. A rating of seven indicates the most natural response.

Within Slovenia, the largest difference in naturalness ratings was for the WPC with imitation growth rings. In Koper, this specimen was rated higher (4.20 scale points) than in Ljubljana

(2.98 scale points). The stone tile specimen was rated noticeably higher in Ljubljana than in Koper (6.35 and 5.72 respectively).

Table 14: Mean naturalness ratings with 95 % Bonferroni adjusted confidence intervals for the two groups from Slovenia.

	Koper, Slovenia		Ljubljana, Slovenia	
Specimen	Mean	95 % CI	Mean	95 % CI
Clear pine, rough sawn	6.25	5.65-6.68	6.47	5.82-6.85
Knotty pine, planed	6.33	5.71-6.66	6.51	6.00-6.95
Clear pine, planed	6.07	5.61-6.66	6.44	5.48-6.52
Stone tile, untreated	5.72	4.82-6.20	6.35	5.25-6.62
Ash, HW, untreated	5.62	4.89-6.07	5.44	5.18-6.34
OSB	5.24	4.43-5.62	5.00	4.85-6.03
Brick tile	4.62	3.86-5.42	4.95	3.83-5.37
MDF, growth rings, white	4.47	3.51-4.81	3.89	4.11-5.40
Cork	4.31	3.79-5.10	4.29	3.53-4.84
Particleboard	4.41	3.93-5.12	4.16	3.71-4.88
Painted planed pine (white)	3.77	2.84-4.00	4.15	3.54-4.68
MDF, untreated	3.86	3.33-4.52	3.83	3.22-4.38
WPC, growth rings	4.20	3.29-4.61	2.98	3.78-5.06
Woven wool fabric	3.72	2.95-4.26	3.56	3.19-4.49
Leather, untreated	3.32	2.53-4.12	3.20	2.52-4.10
Painted MDF (white)	3.18	2.51-3.77	3.19	2.60-3.85
Wallpaper, white	3.20	2.51-3.68	2.84	2.74-3.89
Woven fabric	2.79	2.14-3.26	2.67	2.33-3.44
Ceramic tile, white	2.50	1.75-3.09	2.38	1.92-3.24
Steel, painted white	2.26	1.68-2.78	1.82	1.75-2.84
Plastic, polished	1.97	1.49-2.75	2.07	1.20-2.44
Steel, milled surface	2.16	1.59-2.69	1.71	1.63-2.72

The difference in mean naturalness ratings were statistically significant for only five specimens (Table 11). There were no statistically significant differences between ratings from Koper and Ljubljana, and only one statistically significant difference between Finland and Norway. There was moderate evidence that particleboard was rated as more natural in Norway (mean: 4.14; 95% CI: 3.61-4.72) than in Finland (mean: 3.44; 95% CI: 3.07-3.91) (p-value: 0.031, Table 15). There was strong evidence particleboard was rated differently in Finland (mean: 3.44; 95% CI: 3.07-3.91) and Slovenia (mean: 4.41; 95% CI: 3.90-4.92) (p-value: 0.002). There was also strong evidence WPC with imitated growth rings was rated differently between the Norwegian (mean: 2.98; 95% CI: 2.37-3.59) and Slovenian (mean: 4.20; 95% CI: 3.63-4.77) groups (p-value: > 0.001). There was suggestive evidence of a difference in ratings for the WPC with imitated growth rings between Finland (mean: 3.36; 95% CI: 2.90-3.82) and Slovenia (mean: 4.20: 95% CI: 3.63-4.77) (p-value: 0.049). Brick tile was rated differently between Finland (mean: 5.45; 95% CI: 4.90-6.00) and Slovenia (mean: 4.62; 95% CI: 3.95-5.29) as well, though with only suggestive evidence (p-value: 0.044). Untreated MDF was rated differently between Finland (mean: 3.29; 95% CI: 2.87-3.70) and Slovenia (mean: 3.86; 95% CI: 3.35-4.37), with moderate evidence of the difference (p-value: 0.023). Finally, there was suggestive evidence (p-value: 0.048) of a difference in the ratings of the Ash heartwood sample between Norway (mean: 5.62; 95% CI: 5.11-6.13) and Slovenia (mean: 4.62; 95% CI: 3.95-5.29). Ash heartwood was the only solid wood material with a statistically significant difference in naturalness ratings.

Table 15: Specimens with statistically significant results (p-value < 0.05, including Bonferroni adjustments) with p-values derived from the Pairwise Wilcoxian Rank Sum test comparing countries, and comparing Koper to Ljubljana within Slovenia

Specimen	Koper – Ljubljana	Finland – Norway		Finland – Slovenia		Norway – Slovenia	
Particleboard	-	0.031	*	0.002	**	-	
Brick Tile	-	-		0.044	*	-	
WPC, Growth rings	-	-		0.049	*	>0.001	***
Ash, heartwood	-	-		-		0.048	*
MDF, untreated	-	-		0.023	*	-	

The ratings for the wood, stone, plastic, metal and leather coincide well with the material class ratings found in Fleming, et al. (2013), where images of the wood and stone classes were rated as having high naturalness, leather was rated as having medium naturalness, and plastic and metal were rated as having low naturalness.

4.1.3 Ranking task

The ranking task clearly posed the greatest challenge task for respondents. There were many incidents of specimens being placed on the ranking list multiple times and items being left off the ranking list. Several respondents simply did not finish the task before turning in their paper questionnaire. Approximately 75% of respondents from Espoo, Koper, and Ljubljana completed the ranking task, while approximately 33% of the respondents from Oslo completed the task. The difficulty respondents experienced while completing this task warrants some hesitation in attributing significance to the outcome of the ranking task.

The complete responses indicated strong correlations within Slovenia and between countries. According to Spearman's ρ and Kendall's τ, the strongest correlation was between Koper, Slovenia and Ljubljana, Slovenia, indicating any differences between the two locations are minor ($\rho = 0.983$, $\tau = 0.913$; Table 16, Figure 14). The least correlated rankings varied based on correlation calculation methods. Rankings from Norway and Slovenia were the least correlated according to Kendall's τ (τ = 0.804; Table 16, Figure 15), while the correlation between Finland and Norway was the lowest according to Spearman's ρ (ρ = 0.933; Table 16, Figure 16).

Table 16: Kendall's τ and Spearman's ρ correlation coefficients of the naturalness ranking task for each compared group.

Group	Kendall's τ	Spearman's ρ
Finland vs. Slovenia	0.868	0.962
Finland vs. Norway	0.824	0.933
Norway vs. Slovenia	0.804	0.942
Koper vs. Ljubljana	0.913	0.983

By combined mean rating the rough, clear pine specimen was the ranked as the most natural followed by other pine specimens (Table 17). In all locations except Norway, the rough, clear pine specimen was ranked as the most natural. In Norway, the planed, knotty pine specimen was ranked as the most natural. The stone tile specimen was ranked above the planed Ash specimen in all locations except Slovenia.

Table 17: Mean naturalness rank for each sample by group, ordered by the combined mean rank. Ties are listed as decimal values between sequential ranks (e.g., 12.5 for a two-way tie).

				Slovenia		
Specimen	Combined*	Finland	Norway	Combined	Koper	Ljubljana
Pine, rough, clear	1	1	2	1	1	1
Pine, planed, knots	2	2	1	2	2	2
Pine, planed, clear	3	3	3	3	3	3
Stone tile	4	4	4	5	5	4
Ash, HW, planed	5	6	7	4	4	6
OSB	6.5	7	5	6	6	5
Brick	6.5	5	6	7	9	7
MDF (white), rings	8	8	8	10	10	10
Cork	9	9	9	9	8	9
Particleboard	10	10	10	8	7	8
Painted Pine	11	11	11	14	13	14
WPC, rings	12.5	12	16	11	11	11
MDF, plain	12.5	14	13	12	12	12
Wool fabric	14	15	14	13	14	13
MDF (white)	15	17	12	17	15	18

Woven fabric	16	18	15	15.5	17	15
Wallpaper, white	17	16	18	15.5	16	16
Leather	18	13	19.5	18	18	17
Ceramic Tile	19	19	17	19	19	19
Steel, milled surface	20	21	19.5	21	22	21
Steel (white)	21	20	22	20	20	20
Plastic, polished	22	22	21	22	21	22

* Combined ranking care computed over the full dataset (or subset of the data, in the case of Slovenia's combined ranking) and are not the ranked means of the group rankings.

Within Slovenia, rankings were very similar between Koper and Ljubljana (Table 17, Figure 14). The largest difference in rankings between Koper and Ljubljana was painted white MDF specimen, which was ranked as the 15th most natural specimen in Koper and the 18th most natural specimen in Ljubljana.

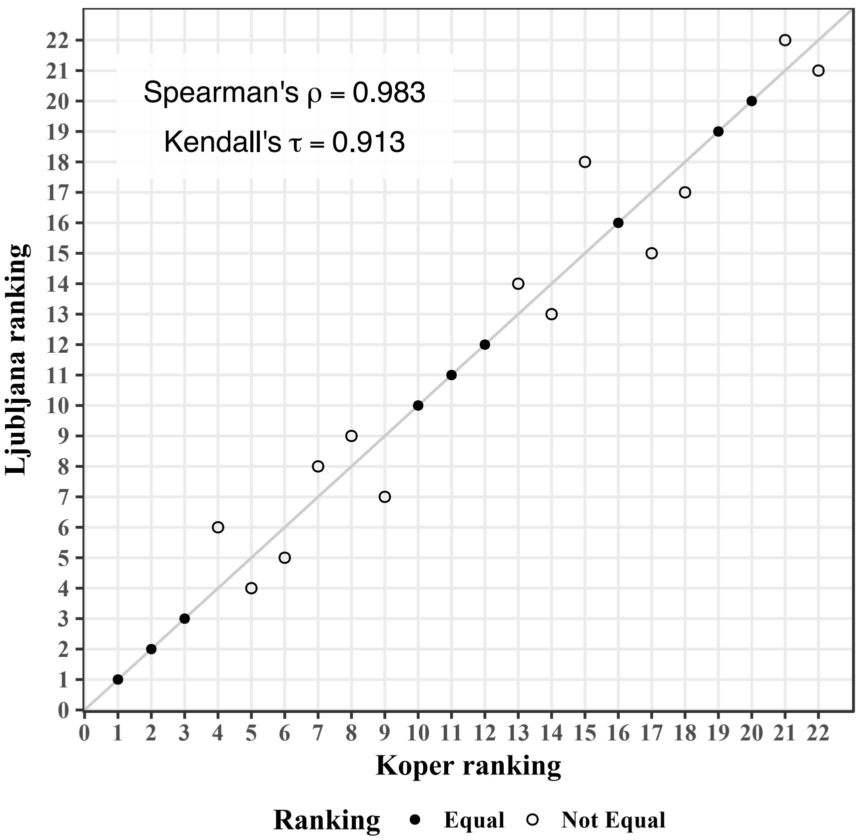


Figure 14: Ranking correlation between Koper, Slovenia and Ljubljana, Slovenia

Only two specimens were ranked equally between Slovenia and Norway (Table 17, Figure 15). These were the planed, clear pine specimen ranked as the third most natural specimen and the cork specimen ranked ninth. In Slovenia, the WPC with imitation growth rings was ranked five positions more natural than in Norway (11 and 16, respectively). This pattern was reversed for the white-painted MDF specimen which was ranked as the 12th most natural in Norway, and the 17th most natural in Slovenia.

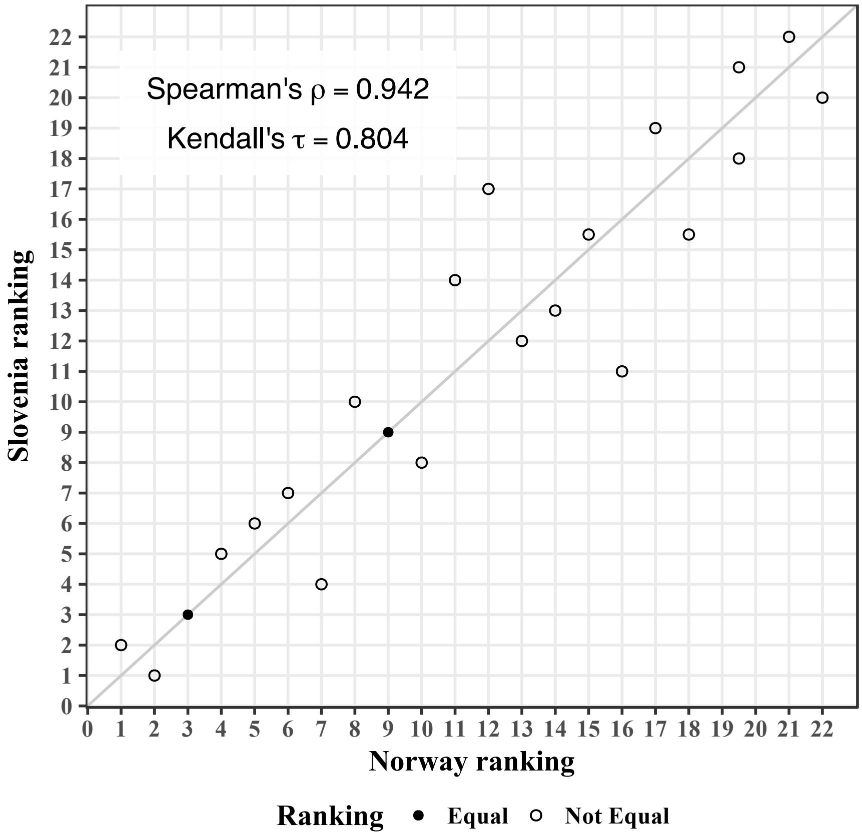


Figure 15: Ranking correlation between Norway and Slovenia.

In Norway and Finland, the correlation between ranks was the greatest between the specimens ranked as most natural (Table 17, Figure 16). The most divergent rankings between Norway and Finland were for the white-painted MDF specimen (12th and 17th respectively) and the leather specimen (tied at rank 19.5, and ranked 13th respectively).

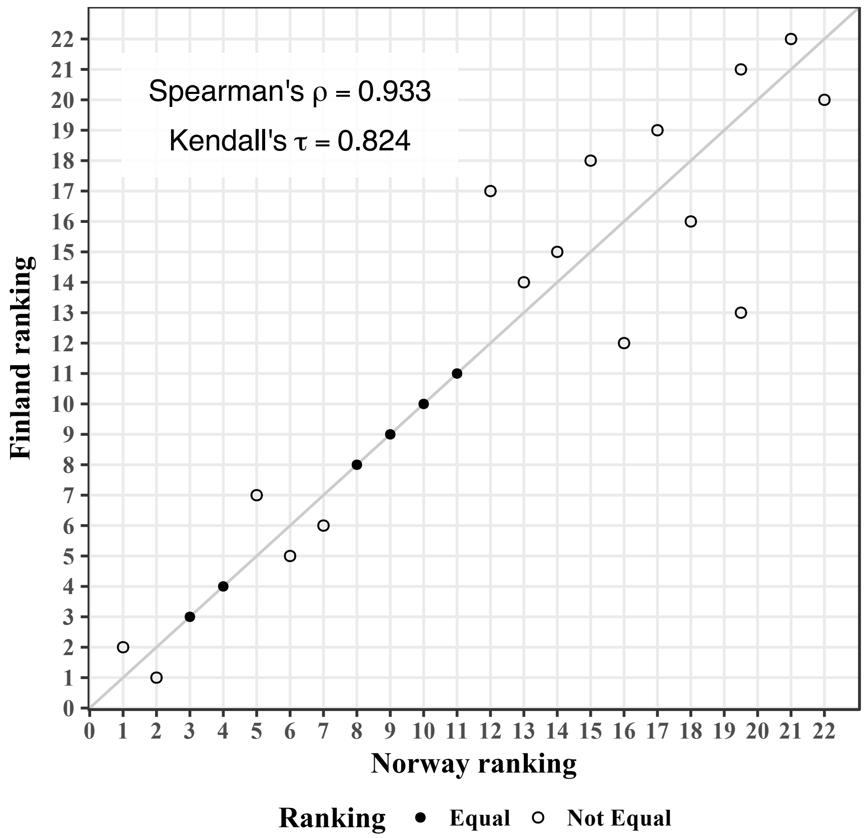


Figure 16: Ranking correlation between Finland and Norway.

The rankings in Finland and Slovenia coincided for the most natural and least natural specimens (Table 17, Figure 17). The most divergent ranks were for the leather sample (13th most natural in Finland, and 18th most natural in Slovenia).

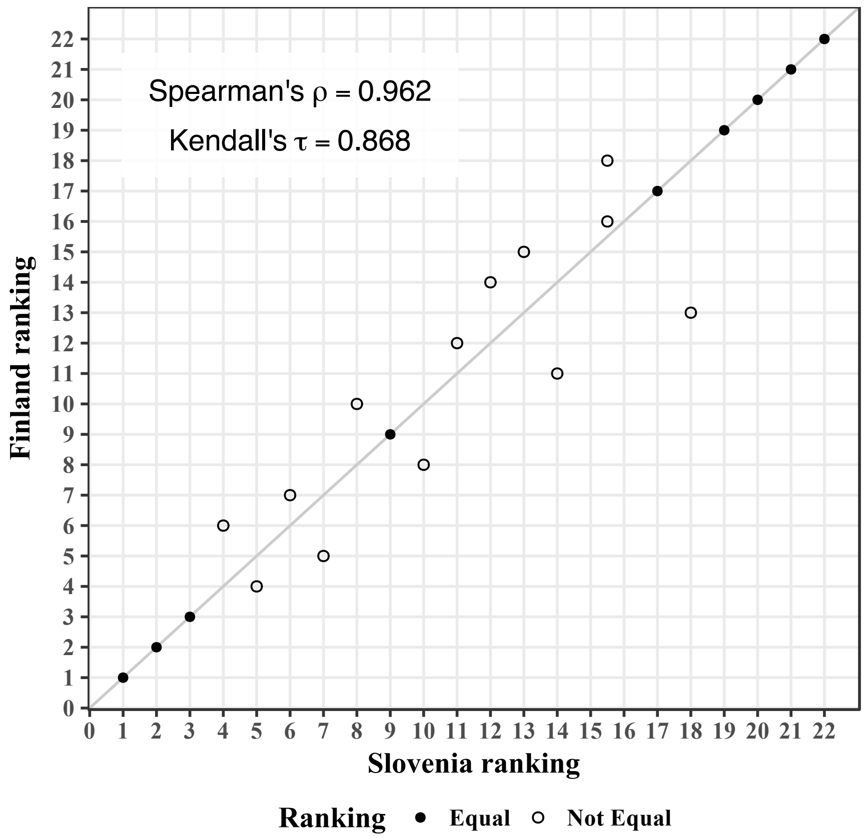


Figure 17: Ranking correlation between Finland and Slovenia.

4.2 Human stress and stress recovery in office-like environments

4.2.1 Experiment efficacy

The goals of this experiment were to create a stress response that could be detected by monitoring heart rate and salivary free cortisol concentration, and then observe the magnitude of the response to the stressor and recovery from it for comparison between test conditions. The stressor, in this case was one of two six minute excerpts from two separate action films, produced visible stress responses of similar magnitudes. There was no detectable difference between cortisol responses to the different videos (two-sided p-value: 0.819).

Cortisol response

The response to the stressor was visible in cortisol concentration changes, typically as an increase in cortisol concentration from the 45th minute to the 60th minute. (Figure 18). In ideal situations, the pattern was similar between the two tests for each subject, but with a detectable difference between the two tests. Following the response to the stressor, indicated by an increase in cortisol concentration, recovery was expected and indicated by a decrease in cortisol concentration by the 75th minute.

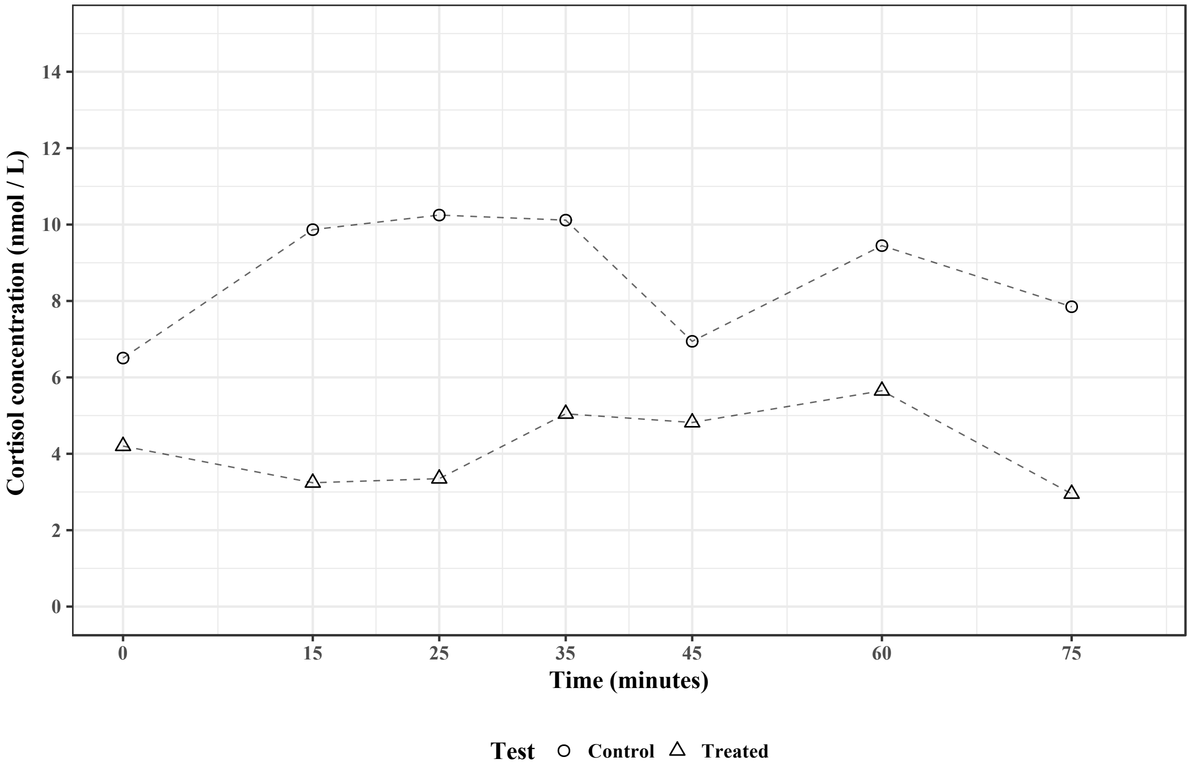


Figure 18: Observed cortisol response pattern for one subject, representing a typical pattern.

However, this pattern was not always observed. Variations of the expected pattern were observed in several cases. These variations included:

- Minor variations in one segment of the test (e.g., the moderate rise in cortisol concentration at the beginning of the test discovered in the control environment (Office A:Control) for subject EZP42 in Figure 19);
- a near continuous decrease in cortisol concentration in one test (e.g., the pattern observed in the wood environment (Office B:Walnut) for subject MHJ36 in Figure 19);
- no evidence of an acclimation period, as in subject UEF59 in Figure 19;
- no noticeable reaction to the stressor, as in the wood environment (Office B:Walnut) for subject MHJ36 in Figure 19; or
- Sharp rises at the beginning of the test, as observed for subject UEF59, which may have indicated feeling stress when coming to take the test (i.e., the test itself was cause a stress reaction before it even began).

Due to these variations, it is important that average responses be analysed and considered carefully. One approach to is to examine both the overall average response throughout the entire test period and the average of only the response period (minutes 45 through 75). This provides a means to ensure events before the test, or any stress caused by coming to participate in the experiment, do not have undo impacts on the results.

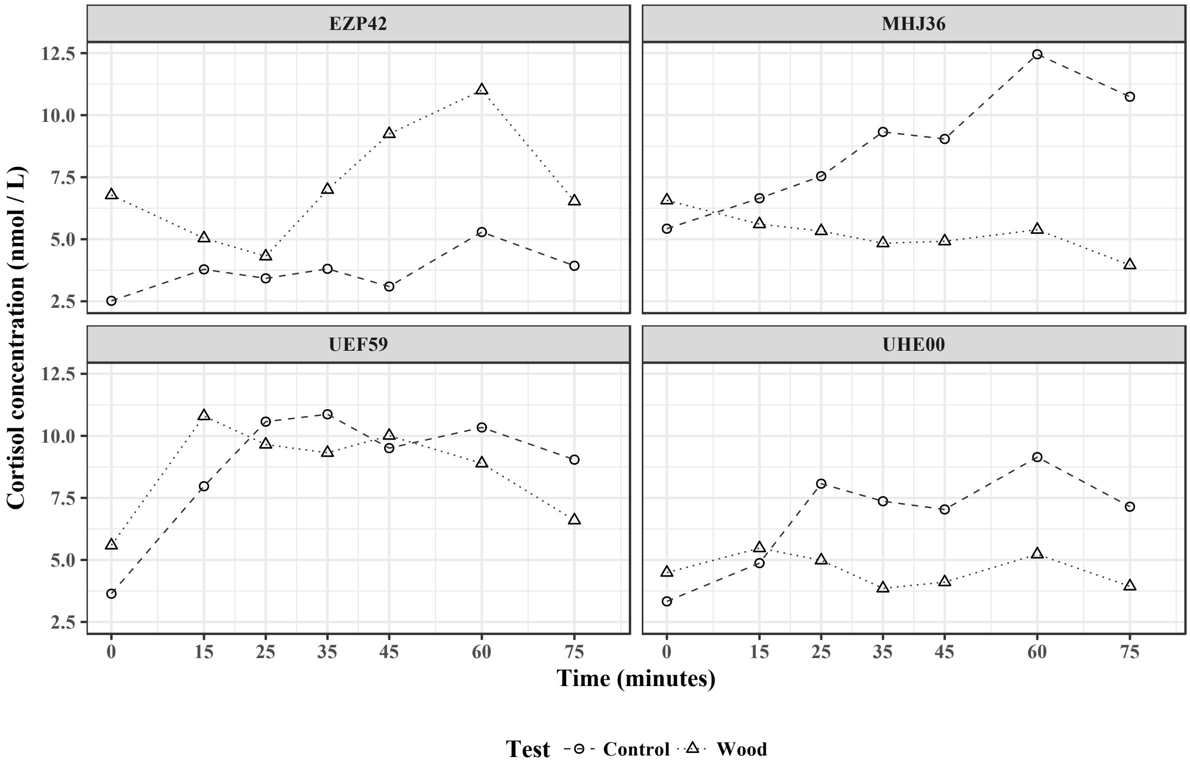


Figure 19: Variations of the expected response pattern observed in the pattern of cortisol concentration measurements through the test full test period.

In addition to the variations on the expected response pattern, several cases produced more ambiguous results. In ambiguous cases, it was difficult to determine if there was a stress response that changed salivary cortisol concentration. This was evident in three typical situations:

1. No identifiable increase during the response period of the test (minutes 45 through 75), as observed in both test environments for subject SVJ44 and in the wood environment (Office A:Oak) for subject TFW50 in Figure 20;
2. a continuous increase in cortisol concentration (as observed in the control environment (Office A:Control) for subject GQK29 in Figure 20; or
3. a significant decrease through the entire test period as in the wood environment (Office B:Walnut) for subject MSL72 in Figure 20.

Although it is tempting associate some ambiguous cases with positive outcomes (i.e., that a lack of a stress response in the treated environment mitigated the effect of the stressor), the presence of the expected response pattern in the majority of cases makes this difficult to support without further evidence.

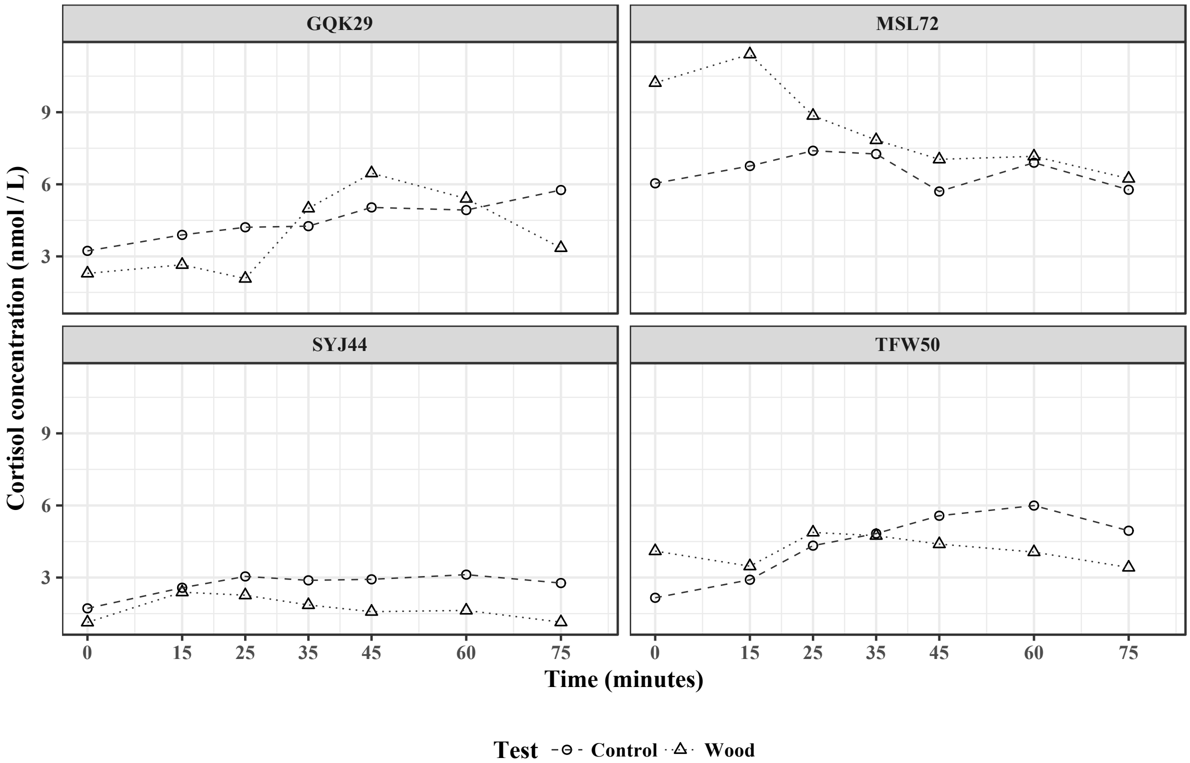


Figure 20: Examples of ambiguous cortisol concentrations patterns observed in the experiment.

Despite any variations or ambiguities present in the cortisol response patterns, this method for monitoring stress proved effective in this experiment. The delayed entry of cortisol into saliva requires extended duration testing, which is a barrier to participation in experiments.

Heart rate

In heart rate responses, the stressor produced a clear pattern as well. However, the response to the stressor was almost immediately visible following the stressor which began immediately following the collection of the saliva sample at minute 15. The immediate effect of cortisol release to counteract the bodies stress response is visible in the heart rate as a dip below the pre-stressor heart-rate (Figure 21). This moderating effect brings the body back to homeostasis very quickly once the stress has passed. While heart rate was useful for verifying the stress response occurred, the poor data quality resulting from intermittent readings and poor or dropped connections between the chest band and the recording device made direct comparisons between tests impractical.

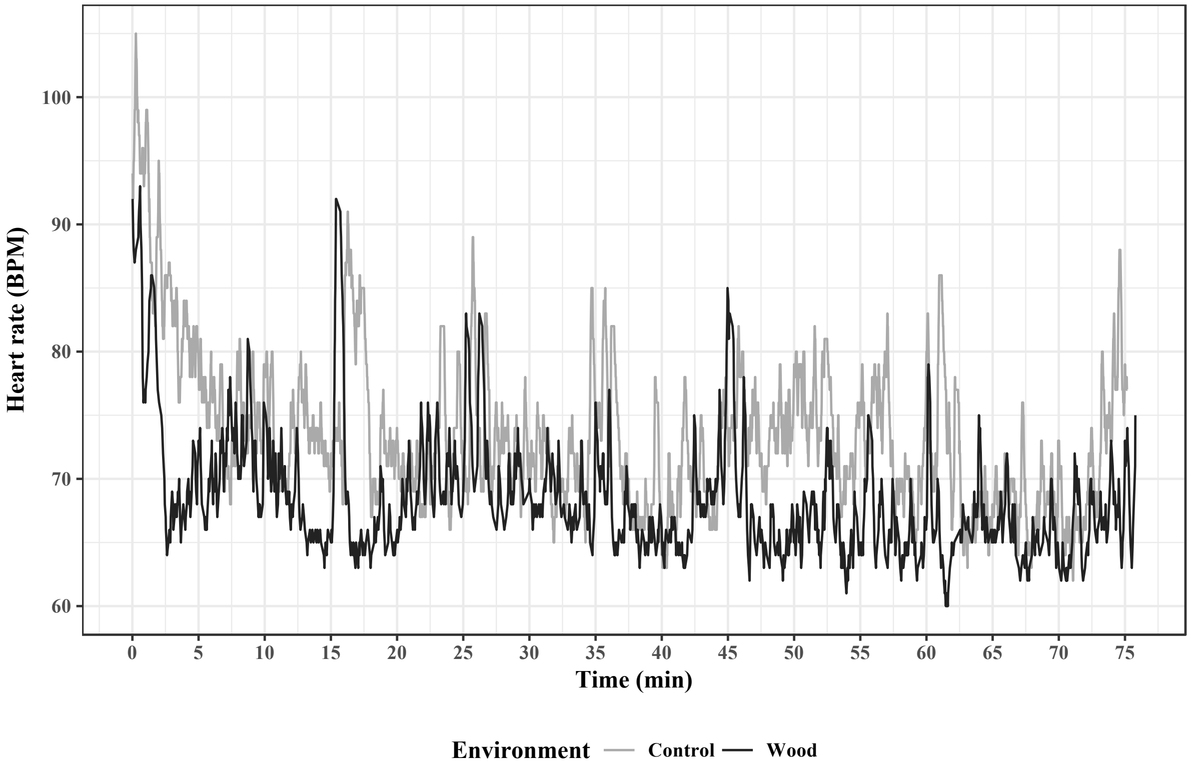


Figure 21: Example heart rate of a participant through both the control and treated tests.

Heart rates often increased sharply when saliva samples were collected (e.g., the sharp heart rate increases at minutes 25, 35, 45, 60, and 75 in Figure 21). The cause of these spikes remains uncertain, but are likely related to either the sudden appearance of the researcher collecting the saliva sample, or the response to the actual process of providing the sample (gently chewing on small swab for 45 seconds).

Proofreading

The proofreading task provided no useful information. The Slovene version of the text, used for 50 subjects, was written in an older style of Slovene that likely caused many more errors to be identified than were inserted purposefully. There was little consistency in what was considered an error between participants, making interpretations of performance on this task difficult. With only 11 subjects using the English version of the text, the sample size wasn't large enough to make meaningful comparisons.

Cortisol analysis

Variations in processing immunoassays to determine the cortisol concentration of collected saliva samples may lead to inaccurate assessment of stress responses. Additionally, the plate-to-plate variability is not well accounted for in hypothesis testing. To mitigate, or, at the very least, understand this source of variability, each plate includes its own calibrators which are used to construct a curve based on known quantities of cortisol. Using this curve, the cortisol concentrations for the calibrators can be recalculated and compared with their known concentrations. This way, the variations between known and calculated values can be assessed. The outcome of this analysis is reasonably positive (Table 18, Figure 22). The most concerning deviations are those between the expected value of 2.76 nmol/L and the calculated mean value of 4.21 nmol/L (153 % difference in concentrations). Not only is this a large deviation relative to the known value, but it lies in the same range as many calculated concentrations for saliva samples.

Table 18: Known and calculated calibrator cortisol concentrations.

Known concentration (nmol/L)	Mean concentration (nmol/L)	Concentration difference (nmol/L)	Concentration difference (%)	Standard deviation	Coefficient of variation
0	0.38	0.38	∞	0.60	1.57
1.38	2.52	1.14	83	0.70	0.28
2.76	4.21	1.45	53	0.78	0.18
13.80	13.97	0.17	1	1.04	0.07
27.60	27.40	-0.20	-1	1.28	0.05
55.20	58.27	3.07	6	1.84	0.03
276.00	285.28	9.28	3	8.43	0.03

While, this may not provide strong confidence that the calculated cortisol concentrations from saliva samples are true concentration values, the consistency between plates is strong enough to provide confidence that a sample calculated to have a cortisol concentration in this range would have approximately the same calculated concentration on another plate. This ensures within-subjects comparisons, and test-to-test quantities should be reliable.

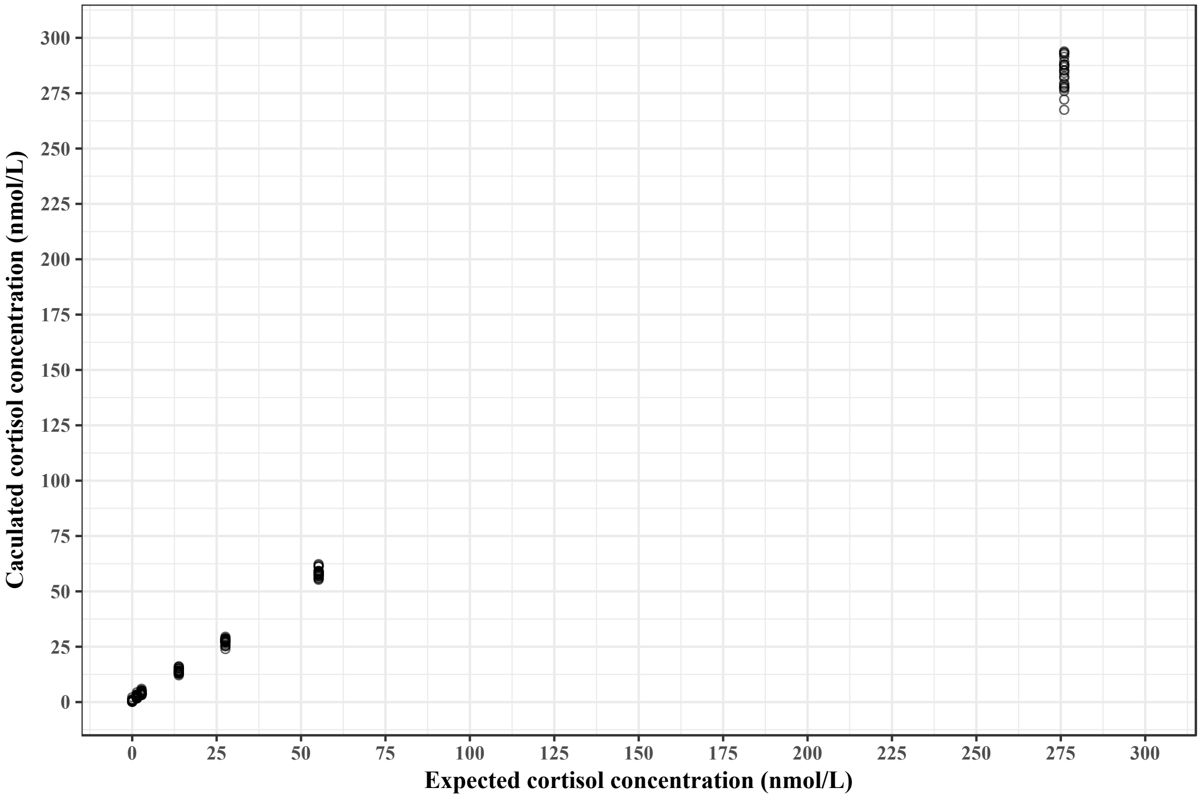


Figure 22: Calculated cortisol concentrations vs expected concentrations for all calibrators.

Individual model fit can be assessed with common tools such as the residual variance in the model or the root mean square error (RMSE). Residual variance is the unexplained variance in the model after fitting, and should be low. RMSE provides an indication of the differences between observed values and predicted values on the scale of the original measure, but is averaged across all of the differences between observations and predictions (it is the square root of the mean of the squared residuals). These indicators, along with the coefficients from the four-parameter log-logistic regression for each microtitre plate are provided in Table 19.

Table 19: Model coefficients and fit indicators. RMSE = Root mean square error.

	Coefficients					
Plate	b	c	d	e	Residual variance	RMSE
1	1.60	-2.69	321.28	0.14	0.42	1.82
2	1.64	-2.85	335.58	0.11	0.19	1.39

3	1.53	-3.29	524.54	0.07	0.12	1.90
4	1.59	-2.33	637.00	0.06	0.19	6.90
5	1.67	-2.12	469.60	0.09	0.48	6.95
6	1.64	-2.37	519.67	0.08	0.51	4.86
7	1.59	-2.22	675.71	0.06	0.17	7.12
8	1.67	-2.13	1162.64	0.05	0.27	4.57
9	1.58	-2.59	684.59	0.06	0.26	6.07
10	1.59	-2.89	402.51	0.09	0.09	1.26
11	1.54	-3.15	405.97	0.09	0.15	3.23
12	1.59	-1.87	971.06	0.06	0.31	6.40
13	1.63	-1.42	1995.97	0.03	2.04	4.62
14	1.67	-2.16	357.61	0.09	0.20	1.09
15	1.54	-2.80	1489.35	0.03	0.30	3.47
16	1.60	-2.33	1087.45	0.04	0.83	2.00
17	1.59	-2.03	1035.11	0.04	0.17	5.32
18	1.48	-3.25	732.77	0.06	0.05	0.61
19	1.62	-2.84	269.89	0.13	0.08	9.22
20	1.53	-3.09	634.19	0.06	0.38	4.42
21	1.65	-2.62	370.98	0.10	0.37	3.18
22	1.64	-2.37	519.67	0.08	0.51	4.86
23	1.63	-2.09	652.24	0.07	0.66	10.99
24	1.51	-2.97	701.88	0.05	0.26	4.35
25	1.72	-2.36	353.45	0.11	0.08	2.36

The controls used on each plate provide another means of assessing the reliability of the output. Unlike the calibrators with precisely known quantities, the cortisol concentration of the controls has an expected range. The controls used in this study included three external controls (saliva samples with known concentration ranges that are separate from the immunoassay kit), which were used on all plates, and two internal controls (saliva samples with known concentration ranges packed with each immunoassay kit) which were used only on the plate they were packaged with. All internal controls were within the expected range (Figure 23).

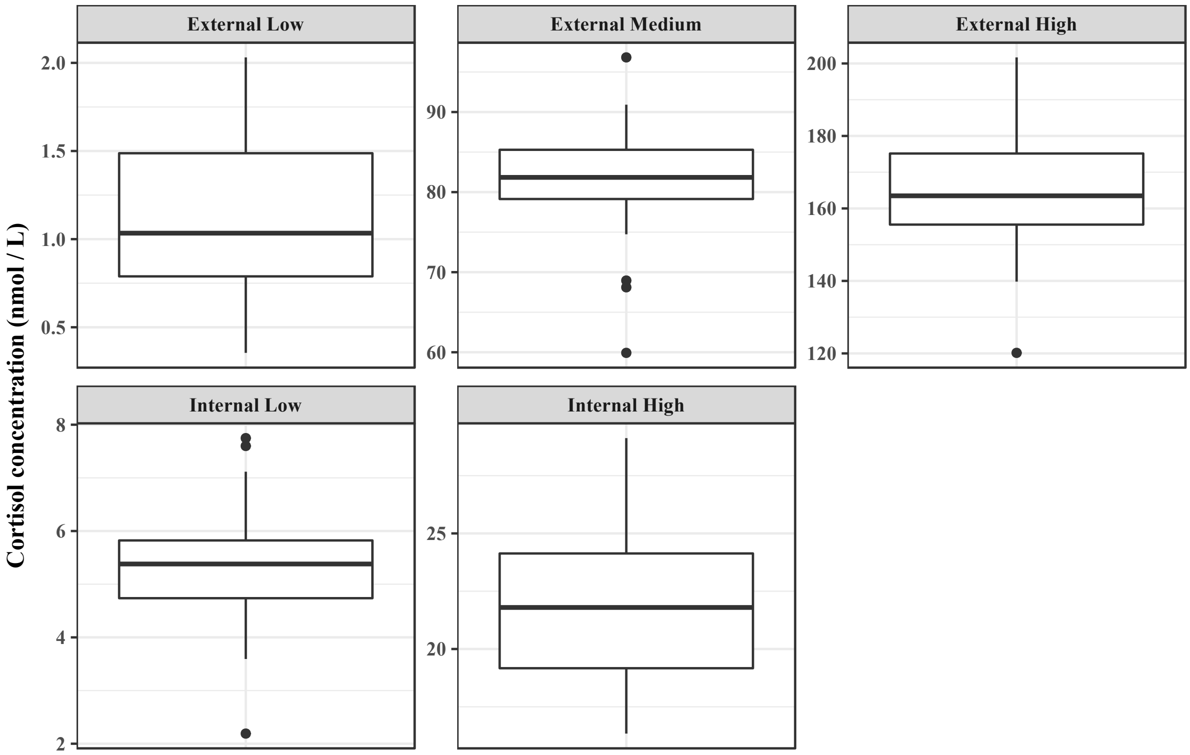


Figure 23: Calculated cortisol concentrations for cortisol controls, all trays

To further validate the plate-to-plate consistency, three full saliva sets (i.e., all seven samples from a single test), were assayed a second time on a second plate. Only one of three saliva sets revealed a concerning difference between measurements, while the other two sets were near the expected amount of variation in this type of biochemical assay (10 %, (Kirschbaum et al. 1995). The mean cortisol concentration calculated in the duplicated assessment for subject XMI10 was 24 % lower in the verification assay than in the original assay (Table 20, Figure 24). This degree of difference is more than some cases of the differences observed within the main dataset. However, replacing the original results with the verification results does not alter the outcome of the significance tests. The original results for all duplicated sets were used in for significance testing and visualisations.

Table 20: Mean absolute and percent difference in cortisol concentrations between assays duplicated on separate trays

Duplicate	Mean absolute difference (nmol/L)	Mean Percent difference (%)
FSE92	0.41	7.91
WTL11	0.62	12.4
XMI10	3.83	24.0

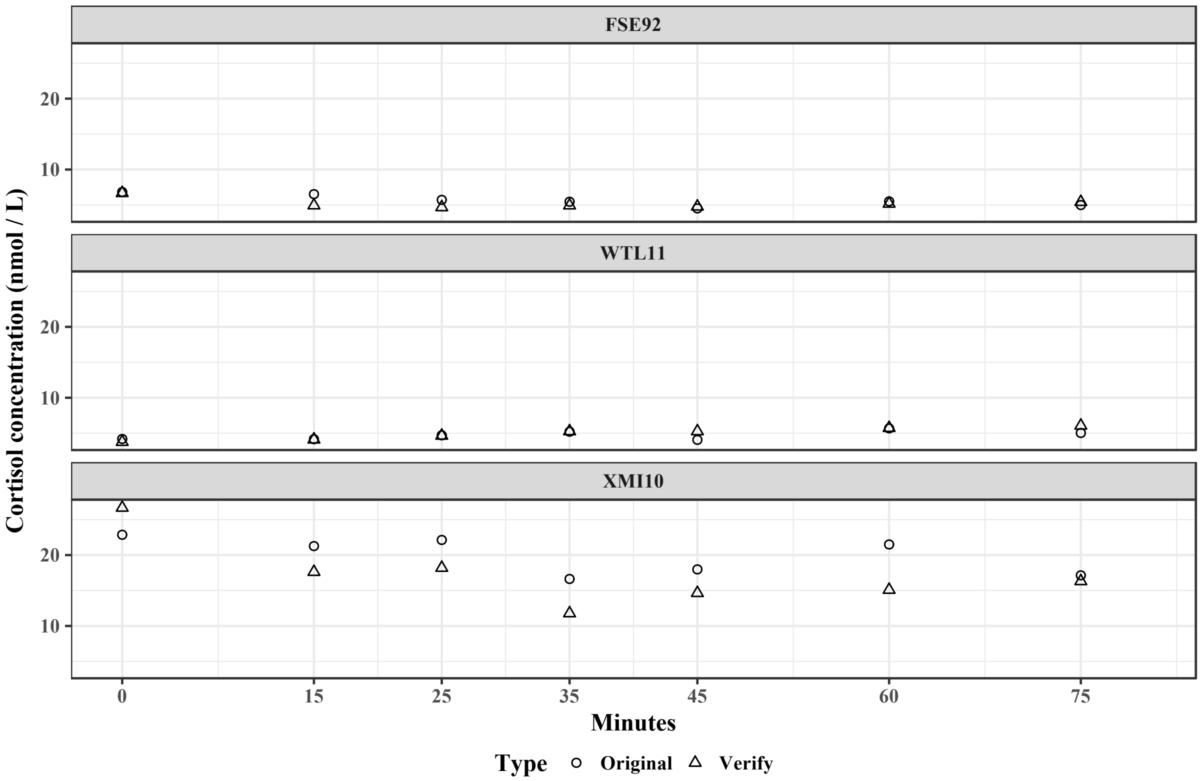


Figure 24: Original and verification readings for the three sample groups assessed on two plates.

WHO-5 well-being index

Reponses to the well-being index were within the expected in all but three cases, where the total score was low enough to raise concern about the subject's overall well-being (scores totalling 32 or lower). In these cases, subjects were notified that their scores were low enough to raise concern, and the option was given to provide contact information for counselling. The test outcomes for these individuals were in line with expectations and they were left in the final analysis.

Summary statistics for the WHO-5 well-being index are provided in Table 21.

Table 21: Overall WHO-5 Well-being index score summary

Room	Test	Mean	Median	Std. Dev.	Min	Max
Office A	Control	62.1	64	18.4	40	88
Office A	Oak	62.8	68	16.3	32	92
Office B	Control	68.9	68	12.4	24	100
Office B	Walnut	65.7	68	15.4	28	100

There was no evidence of a within-subjects difference in WHO-5 Well-being index scores between tests (paired, two-sided p-value: 0.30). A summary of within-subject variation between tests in provided in Table 22.

Table 22: Within-subjects difference in the WHO-5 Well-being index scores between the control test and treated test (Control score - Treated score).

Room	Mean	Median	Std. Dev.	Largest reduction	Largest increase
Oak	- 0.7	0	10.2	-24	12
Walnut	- 3.2	0	9.1	-16	20

4.2.2 Observed data

For the purpose of these cortisol concentration descriptions and comparisons, outcomes are considered positive if the cortisol concentration is lower for the period of interest (i.e., the entire duration, or a subset of the duration) in the associated wood environment than in the control environment. When this is not true, the outcome is considered negative. For example, in Figure 25, the within-subjects difference at each interval are marked "+" when the cortisol concentration at that interval was greater in the control environment than in the wood environment, and "-" otherwise.

However, in the case of recovery, the value compared is the within-subjects difference between the control and wood environment (control value minus value in the wood room). This parameterisation tests the hypothesis that the value in the control environment is greater than in the associated wood environment. In the case of recovery, the tested hypothesis was that recovery would be greater in a wood room. Therefore, that comparison is parameterised to compare the value in the wood environment minus the value in the control environment for each subject.

In both Office A and Office B, there were more positive outcomes than negative in all tested conditions except for recovery, where there were 16 negative and 15 positive outcomes. This indicates wood furniture may produce positive health impacts for the majority office workers in offices without wood furniture by reducing the cortisol response to stressors in the workplace. Common approaches to reducing this type of stress response are therapeutic and social (McEwen 1998), however, these environmental interventions show demonstrable reductions in cortisol response to stress as well.

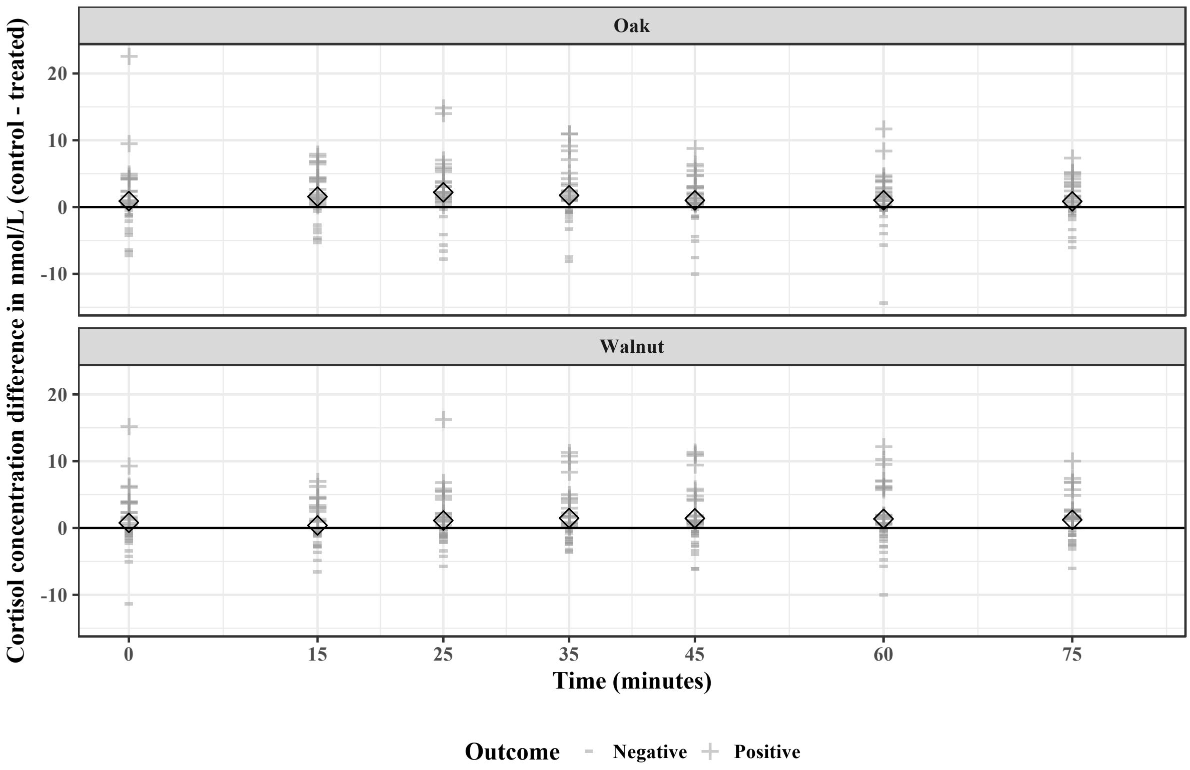


Figure 25: Within-subject differences for all respondents ("+" for positive outcomes, "-" for negative outcomes) and the mean difference for each period (diamonds) in each test environment.

Full test duration cortisol concentration

In Office A:Oak, the mean observed difference in cortisol concentration was 1.34 nmol/L (std. dev.: 3.67) greater in the control environment than in the test environment (Table 23). In the test environment with oak furniture, the mean observed difference in cortisol concentration was 1.21 nmol/L (std. dev.: 3.77), however there were many more negative outcomes in Office B:Walnut than in Office A:Oak (Figure 26).

In Office A, there were 22 tests with positive outcomes (mean cortisol concentration was lower in the wood environment) and 7 negative outcomes. Among the 22 positive outcome tests, the mean difference in cortisol concentration in the control environment was 2.92 nmol/L greater than in the wood environment. In the 7 cases of negative outcomes, the mean cortisol concentration in the control environment was 3.61 nmol/L less than in the wood environment (Figure 26, Table 23).

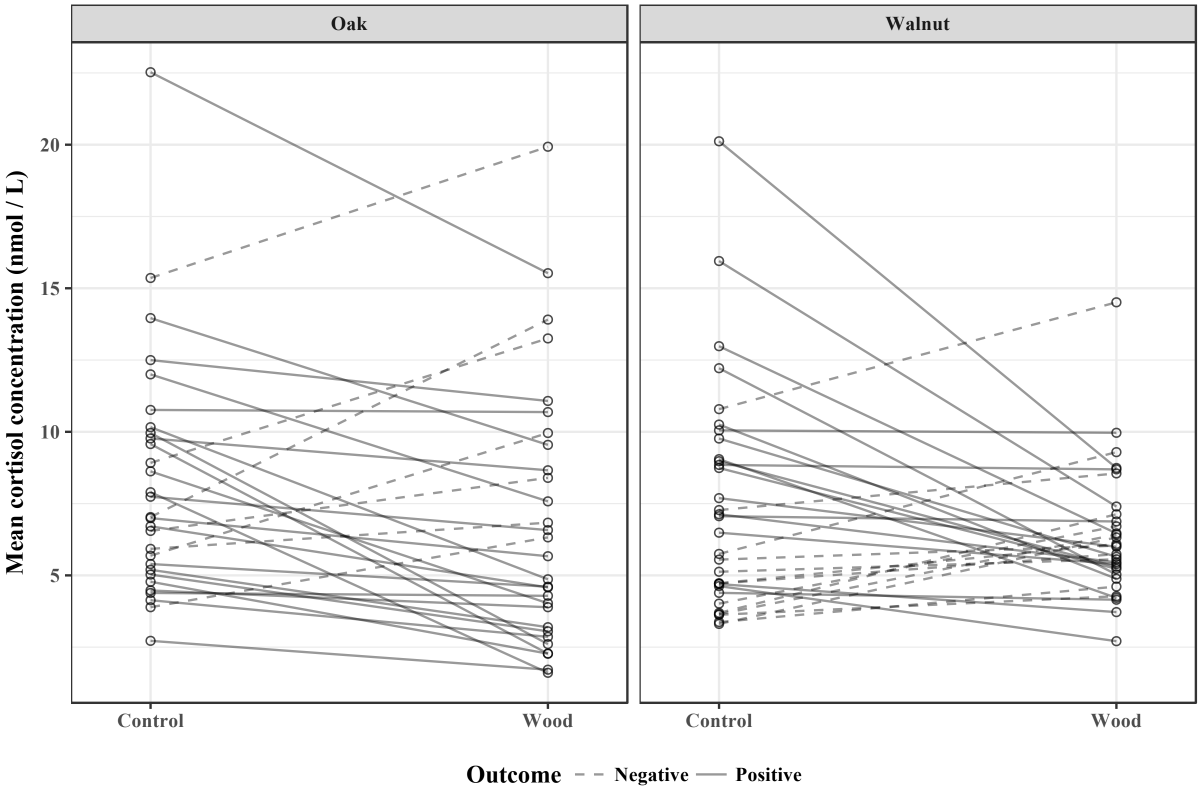


Figure 26: Full test duration mean cortisol concentration comparisons. Circles indicate mean values, lines connect subjects between test environments (control, wood).

In Office B, there were 18 positive and 13 negative outcomes. In the positive outcome cases, mean cortisol concentration was 3.51 nmol/L greater in the control environment than in the wood environment. In the negative outcome tests, mean cortisol concentration was 1.97 nmol/L less in the control environment than in the wood environment (Figure 26, Table 23).

Table 23: Within-subjects difference between the mean cortisol concentration throughout the entire test period. Negative values indicate the mean cortisol concentrations was greater in the wood room.

Environment	Group	Mean (nmol/L)	Standard Deviation	Minimum (nmol/L)	Maximum (nmol/L)	n
Office A	Positive	2.92	2.45	0.08	7.35	22
Office A	Negative	-3.61	2.01	-6.88	-0.91	7
Office A	All	1.34	3.67	-6.88	7.35	29
Office B	Positive	3.51	3.27	0.08	1.38	18
Office B	Negative	-1.97	1.24	-3.72	11.38	13
Office B	All	1.21	3.77	-3.72	11.38	31

Due to the wide range of cortisol concentrations exhibited by individuals, it is helpful to examine the difference between the control and wood test environments on a percent basis. In Table 24, the difference in cortisol concentrations between control and treated environments as a percent of the control environment cortisol concentration indicates the within-subjects difference varied greatly.

Table 24: Within-subjects difference between the mean cortisol concentration throughout the entire test period as a percent of the concentration in the control room. Negative values indicate the mean cortisol concentrations was greater in the treated room.

Environment	Group	Mean (%)	Standard Deviation	Minimum (%)	Maximum (%)	n
Office A	Positive	34.17	23.02	0.01	79.65	22
Office A	Negative	- 51.07	29.30	- 97.82	- 15.40	7
Office A	All	13.60	44.27	-97.82	79.65	29
Office B	Positive	32.41	20.74	0.01	58.84	18
Office B	Negative	- 43.33	30.62	- 93.06	- 8.46	13
Office B	All	0.01	45.41	- 93.06	58.84	31

Response period cortisol concentration

The response period is the 4th, 5th, 6th, and 7th intervals, which includes four saliva samples taken at minutes 35, 45, 60, and 75. The response period is the period when cortisol concentrations are expected to be influenced by experiment. This period includes the acclimated cortisol response and, when present, the stress and recovery responses.

During the response period, there were 19 positive responses and 10 negative responses in Office A, while in Office B there were 17 positive and 14 negative responses. In Office A, the mean cortisol concentration for the response period was 1.15 nmol/L greater in the control environment than in the wood environment (std. dev.: 3.72). In Office B, the mean cortisol concentration was 1.38 nmol/L (std. dev.: 4.06) for the same period. Despite the greater cortisol concentration difference in Office B, the number of negative outcomes was greater than in the oak room, producing more uncertainty about the overall effect in this environment.

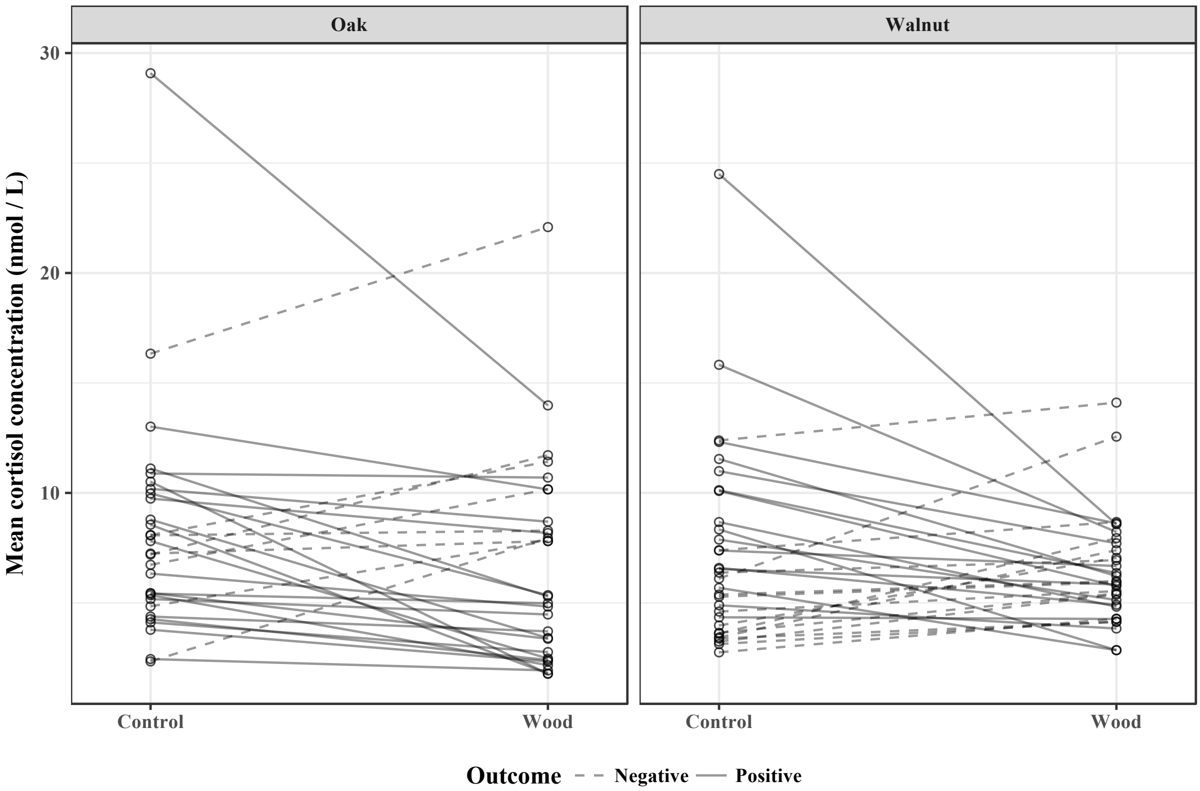


Figure 27: Response period (intervals, 4, 5, 6, and 7; minutes 35 through 75) cortisol concentrations.

The range of within-subject differences also varied between Office A and Office B. These differences are present in their raw values in Table 25, and as a percent of the cortisol concentration in the control environment in Table 26.

Table 25: Within-subjects difference between the mean cortisol concentration during the response period. Negative values indicate the mean cortisol concentrations was greater in the wood room.

Environment	Group	Mean (nmol/L)	Standard Deviation	Minimum (nmol/L)	Maximum (nmol/L)	n
Office A	Positive	3.07	2.38	0.63	8.86	19
Office A	Negative	- 2.50	3.01	- 8.65	- 0.01	10
Office A	All	1.15	3.72	-8.65	8.86	29
Office B	Positive	4.11	3.37	0.58	9.34	17
Office B	Negative	- 1.94	1.58	- 5.22	- 0.06	14
Office B	All	1.38	4.06	-5.22	9.33	31

In both Office A and Office B there was a single case where the magnitude of the difference between the control and wood environments was double the value in the control environment (values less than -100 in Table 26). In both of these cases, the cortisol concentration during the response period was greater in the wood environment.

Table 26: Within-subjects difference between the mean cortisol concentration during the response period as a percent of the mean concentration in the control room. Negative values indicate the mean cortisol concentrations was greater in the wood room.

Environment	Group	Mean (%)	Standard Deviation	Minimum (%)	Maximum (%)	n
Office A	Positive	37.56	22.93	4.51	80.10	10
Office A	Negative	- 33.08	42.01	- 125.3	- 0.01	19
Office A	All	13.20	45.53	- 125.3	80.10	29
Office B	Positive	37.23	19.62	10.21	67.60	14
Office B	Negative	- 39.25	33.22	- 109.5	- 1.07	17
Office B	All	0.03	46.70	- 109.5	67.60	31

Response magnitude

Another indicator of interest is the magnitude of the stress response itself. Examining this value can reveal if the size of the stress response differs between the control and wood environments. In this experiment, the magnitude of the stress response is the difference between the maximum cortisol concentration observed at minute 45, 60, or 75 and the minimum cortisol concentrated observed at minute 35 or 45. This value is then compared between the control and wood test environments for each subject. Positive values indicate the magnitude of the stress response was greater in the control environment than in the wood environment. In this parametrisation, it is possible that the observed magnitude is calculated as the cortisol concentration at minute 45 minus the cortisol concentration at minute 45. There was only one case where this occurred in both test environments. This case was observed in Office A; the cortisol response showed no noticeable stress response in the control environment, and what could have been a delayed stress response in the wood environment (Figure 28). There were 16 other cases where this occurred in one of the two test environments.

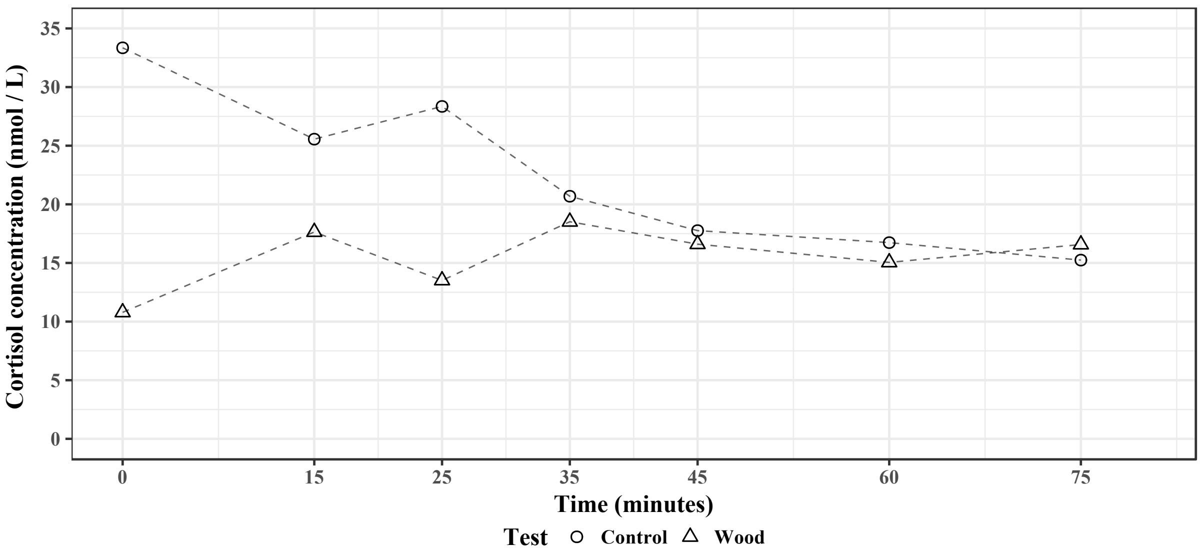


Figure 28: Cortisol concentration of the individual tested with no detectable stress response in either the control or treated environment.

In Office A, there were 16 positive outcomes, 12 negative outcomes, and 1 neutral outcome (magnitude equal to zero). In Office B, there were 20 positive outcomes, and 11 negative outcomes. The mean magnitude of the stress response in Office A was - 0.28 nmol/L (std. dev.: 2.23) and in Office B was 0.36 nmol/L (std. dev.: 1.88). In Office A, the observed magnitude ranged from - 6.78 to 5.48 nmol/L, while in Office B the magnitude ranged from - 4.81 to 4.19 nmol/L (Table 27).

Table 27: Within-subjects difference between the magnitude of the stress response (in nmol/L cortisol concentration). Negative values indicate the magnitude of the stress response was greater in the wood room. Neutral response not included in calculations.

Environment	Group	Mean (nmol/L)	Standard Deviation	Minimum (nmol/L)	Maximum (nmol/L)	n
Office A	Positive	1.05	1.36	0.02	5.48	16
Office A	Negative	-2.09	1.99	- 6.78	- 0.13	12
Office A	All	- 0.28	2.23	- 6.78	5.48	28
Office B	Positive	1.40	1.22	0.46	4.19	20
Office B	Negative	- 1.53	1.29	- 4.81	- 0.26	11
Office B	All	0.36	1.88	- 4.81	4.19	31

Overall, the pattern of responses is less clear in this case than in either the full test duration means or response period means (Figure 29). It is also worth noting in the case of stress response magnitudes, the number of positive outcomes was greater in the walnut environment was greater than in the oak room, the opposite pattern observed in the response period or full test duration means.

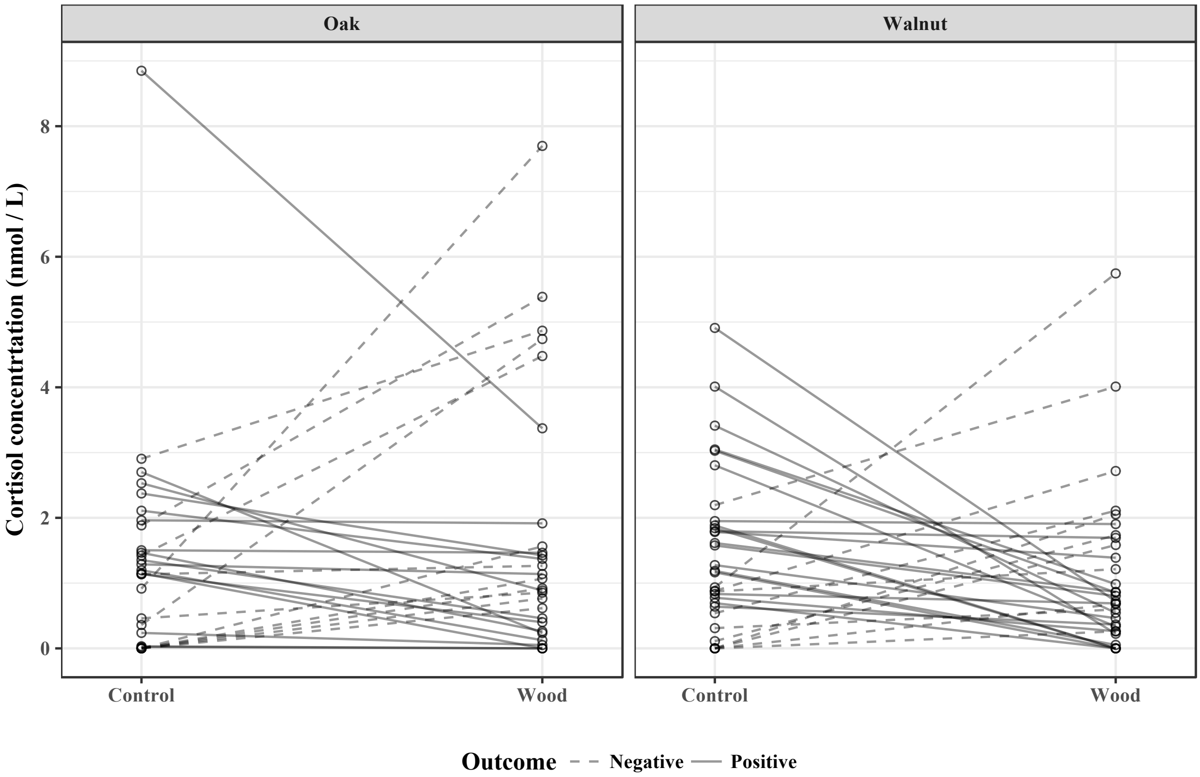


Figure 29: Magnitude of response to the stressor.

Recovery magnitude

The magnitude of recovery is the difference between the maximum cortisol concentration observed in saliva samples from the 35th, 45th, 60th, and 75th minute and the observed cortisol concentration at the 75th minute. This parameterisation introduces the possibility of recovery magnitudes equal to zero when the peak cortisol concentration observed is at the 75th minute. This occurred in 12 cases, six in Office A and six in Office B. In both Office A and Office B the recovery magnitude was observed to be zero three times in the control environment and three times in the wood environment.

The mean recovery observed in Office A was a difference of 0.42 nmol/L cortisol concentration (std. dev.: 3.17) between the control environment and the wood environment. In Office B, mean recovery was a difference in cortisol concentration of 0.60 nmol/L (std. dev.: 2.44) (Table 28). There was no readily apparent pattern indicating that recovery magnitude was greater or there were more positive or negative outcomes in either the oak or walnut room, or in the control environments compared to the wood environments (Figure 30).

Table 28: Within-subjects difference between the magnitude of the stress recovery (in nmol/L cortisol concentration). Negative values indicate the magnitude of the stress response was greater in the wood room.

Environment	Group	Mean (nmol/L)	Standard Deviation	Minimum (nmol/L)	Maximum (nmol/L)	n
Office A	Positive	2.56	1.82	0.71	6.98	16
Office A	Negative	- 2.23	2.38	- 9.07	- 0.12	13
Office A	All	0.42	3.17	- 9.07	6.98	29
Office B	Positive	2.65	1.72	0.04	6.53	15
Office B	Negative	- 1.32	0.97	- 3.37	- 0.12	16
Office B	All	0.60	2.44	- 3.37	6.53	31

The number of positive and negative responses was nearly even in the case of recovery for both test environments. There were 16 positive outcomes and 13 negative outcomes in Office A and 15 positive outcomes and 16 negative outcomes in Office B.

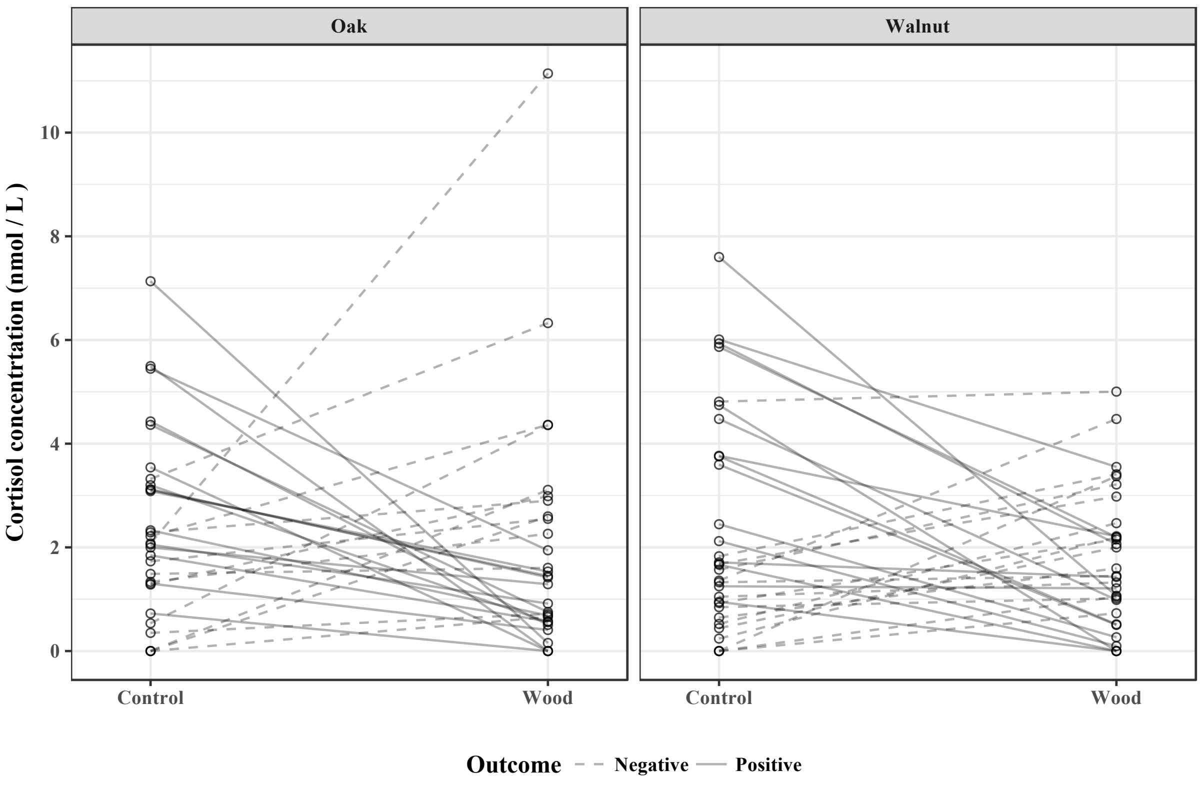


Figure 30: Recovery magnitude from the stress event as observed in cortisol concentration (nmol/L).

4.2.3 Hypothesis testing

Hypotheses were tested using the Wilcoxon signed rank test to look for statistically significant differences between values of interest. P-values less than 0.05 indicate a statistically significant difference. All significance tests were constructed as 1-sided, paired tests. Therefore, reported confidence intervals are 1-sided and range from a single value to infinity. The effect size reported is the median of the difference between each value in one group and every value in the other group (i.e., each value in the control environment is compared to all values in the treated environment, and the median result is reported).

The hypotheses tested were:

1. Cortisol concentration will be greater in the control environments than in the wood environments for both wood furniture types throughout the entire test period.
2. Cortisol concentration will be greater in the control environments than in the wood environments for both wood furniture types during the response period (minutes 35 through 75).
3. Maximum stress during the response period (minutes 35 through 75) will be greater in the control environments than in the wood environments for both wood furniture types.
4. Recovery from maximum stress during the response period (minutes 35 through 75) will be greater in the wood environments than in the control environments for both wood furniture types.

Hypotheses one and two test the theory that the presence of wood in an office space can produce reductions in overall stress levels. Hypothesis three tests the theory that the presence of wood in an office space can reduce the response to stress by reducing the maximum stress felt. Hypothesis four tests the theory that recovery from stress will occur more rapidly in offices with wood furniture.

Hypothesis 1, full test duration means

This comparison tests the within-subjects difference in mean cortisol concentration between the control and wood test environments in each room for the full test duration. The full duration includes cortisol responses caused by the subject's state prior to the beginning of the test. The results indicate that mean overall cortisol concentration was greater in Office A:Oak than in Office A:Control (p-value: 0.015, 95 % 1-sided CI: greater than 0.25 nmol/L). There was no statistically significant difference in mean overall cortisol concentration between the Office B:Walnut and Office B:Control (p-value: 0.105). These comparisons are summarised in Table 29.

Table 29: Full test mean cortisol concentration comparison results. * = significant at the 0.05 level.

Comparison	Median difference (nmol/L)	95 % CI (1-sided)	p-value
Office A:Control – Office A:Oak	1.33	0.25 to ∞	0.015 *
Office A:Control – Office A:Walnut	0.85	- 0.23 to ∞	0.105

Since this comparison includes period of the experiment where observed cortisol concentrations are most likely in relation to events preceding the beginning of the test (or, perhaps cause by anxiety related to participating the test), the baseline period was also compared. There was moderate evidence the mean cortisol concentration in saliva samples collected at minutes 0, 15, and 25 was lower in Office A:Oak than in Office A:Control (median difference, 1.28 nmol/L, p-value: 0.028; 95 % 1-sided CI: median difference > 0.313 nmol/L), while there was no evidence of a difference between Office B:Walnut and Office B:Control (Table 30).

These findings reflect skin conductance responses (frequency of non-specific skin conductance responses) reported by (Fell 2010) where an office-like environment with wood was found to reduce stress responses to the paced auditory serial addition task (PASAT) compared to a control environment at all periods of the experiment (baseline, test response, and recovery). Furthermore, these findings are similar to the reduced endocrine stress response found in Gaab et al. (2003), where the intervention between tested groups was therapeutic in nature (cognitive-behavioural training) as opposed to environmental.

Table 30: Mean cortisol concentration comparison results for minutes 0, 15, and 25. * = significant at the 0.05 level.

Comparison	Median difference (nmol/L)	95 % CI (1-sided)	p-value
Office A:Control – Office A:Oak	1.28	0.31 to ∞	0.028 *
Office A:Control – Office A:Walnut	0.76	- 0.51to ∞	0.173

This outcome confuses the results as it makes it more difficult to attribute any experimental parameters as the reason for a difference in observed stress. However, the response period means (minutes 35 through 75) provides further evidence that the experimental stress and stress response differed between test conditions.

Hypothesis 2, response period means

This comparison tests the within-subjects difference between mean cortisol concentration for the response period, which includes four saliva samples from minutes 35 through 75. This is the period during which the experimental environment and conditions should be reflected in the cortisol concentration of the saliva samples collected. There was evidence that within-subjects difference in cortisol concentration for the response period was lower in Office A:Oak than in Office A:Control (p-value: 0.017; 95 % 1-sided CI: median difference > 0.23 nmol/L). There was no evidence of a difference between Office B:Walnut and Office B:Control (p-value: 0.108) (Table 31).

Table 31: Response period (intervals, 4, 5, 6, and 7; minutes 35 through 75) cortisol concentration comparison results.

Comparison	Median difference (nmol/L)	95 % CI (1-sided)	p-value
Office A:Control – Office A:Oak	1.15	0.23 to ∞	0.017 *
Office A:Control – Office A:Walnut	0.98	-0.16 to ∞	0.108

In a previous study by Fell (2010), evidence was found that the frequency of nonspecific skin conductance responses were lower in the wood test environment compared to the control environment, matching the results for Office A. In Fell's 2010 study, the wood furniture used was light in colour (birch veneer with a clear finish), more like the oak furniture used in Office A:Oak than the walnut furniture used in Office B:Walnut.

Hypothesis 3, response magnitude

This comparison examines the magnitude of the stress response observed during the test period. This magnitude of the stress response is the maximum cortisol concentration of minutes 45, 60, and 75 minus the minimum cortisol concentration of minutes 35 and 45 measured in nmol/L. There was no evidence of a within-subjects difference between control and wood environments in either Office A or Office B (p-values: 0.558 and 0.085, respectively) (Table 32).

Table 32: Response magnitude cortisol concentration comparison results.

Comparison	Median difference (nmol/L)	95 % CI (1-sided)	p-value
Office A:Control – Office A:Oak	- 0.05	- 0.76 to ∞	0.558
Office A:Control – Office A:Walnut	0.40	- 0.14 to ∞	0.085

Unlike the salivary free cortisol response results reported in Gaab et al. (2003), which reported a difference in response magnitude between test groups (those receiving cognitive-behavioural training before the experiment and those receiving it after), this study produced no evidence of a difference between either control and wood test environments.

Hypothesis 4, recovery magnitude

Recovery magnitude is the difference in cortisol concentration between the maximum observed cortisol concentration from minutes 35, 45, 65, and 75 minus the cortisol concentration observed at minute 75. The within-subjects difference between recovery magnitude in the control environment and wood environment was then compared for room. There was no evidence that the recovery magnitude was greater in either wood environment compared to their respective control environments (Office A p-value: 0.838; Office B p-value: 0.855) (Table 33).

Table 33: Recovery magnitude cortisol concentration comparison results.

Comparison	Median difference (nmol/L)	95 % CI (1-sided)	p-value
Office A:Control – Office A:Oak	- 0.47	- 1.45 to ∞	0.838
Office A:Control – Office A:Walnut	- 0.52	- 1.27 to ∞	0.855

No substantial difference was observed or detected in the recovery from stressor through changes in salivary free cortisol concentration, however, this may be due to short duration of the test period preventing recovery that occurred after the end of the test from being detected, or it may be caused by time gap between measurements taken during the response and recovery period (minutes 35 to 75).

5 DISCUSSION AND CONCLUSIONS

Building occupants are impacted by their environment physically and psychosocially (Dolan, Foy, and Smith 2016). Their perceptions of their environment and the materials in at are based on visual recognition, haptic response, scents, and other sensory inputs (Bhatta and Kyttä 2016; Burnard et al. 2017; Burnard 2017). The principles of biophilic design suggest including natural elements into the built environment will lead to improved health outcomes for building users, and it is therefore important for users to perceive their environment as natural (Wilson 1984; Kellert and Wilson 1993; Kellert 2008). Understanding how building users perceive the naturalness of building materials is therefore critical to understanding how to use materials to realise the benefits of biophilic design.

The building material naturalness study examined respondent perceptions of the perceived naturalness of 22 building materials in three countries. Results conclude that wood and stone were consistently perceived as natural in all three locations, but that perceptions of some imitation materials varied between countries. Additionally, findings suggest that the degree of transformation a material has been through is directly related to its perceived naturalness with materials undergoing greater degrees of transformation being perceived as less natural than materials presented closer to their raw state. These findings were originally reported in Burnard et al. (2017).

Following determination that wood was considered as the most natural product of those presented, a study of human stress responses was conducted to compare stress responses in offices with wood furniture to stress responses in offices with non-wood furniture. Three types of furniture were compared: oak, a light-coloured wood with clearly visible grain pattern; walnut, a dark-coloured wood with noticeable, yet not as pronounced grain patterns; and plain white (non-wood). The plain white furniture was the control environment for a within-subjects experiment that monitored reactions to and recovery from an emotion induction stress event using salivary free cortisol as the primary indicator of stress level over a 75-minute period. Results indicate the oak furniture test environment produced statistically significant stress reduction compared to the control environment, indicating environmental interventions may lead to reduced stress levels in offices.

5.1 Building material naturalness

Materials consistently rated as more natural by respondents had less apparent transformation. Solid wood, for example, was rated as more natural than its processed counterparts such as OSB, particleboard, and MDF. This was also true of unrelated materials that had gone through more or less transformation during production. Stone, brick, and solid wood were all consistently rated as more natural than metal, plastics, and even fabric. These perceptions of naturalness are consistent with previous research on foodstuffs and building materials (Rozin 2005; Rozin, Fischler, and Shields-Argelès 2012). Within the collection of wood-based materials, the relationship between degree of transformation and perceived naturalness is most clear. The materials with more easily recognised wood components had undergone less transformation and were rated as more natural. OSB was ranked above particleboard, which was ranked above MDF. In this case, each material has gone through a greater degree of transformation than the previous material, and the ability to recognise individual components is diminished (Figure 31).

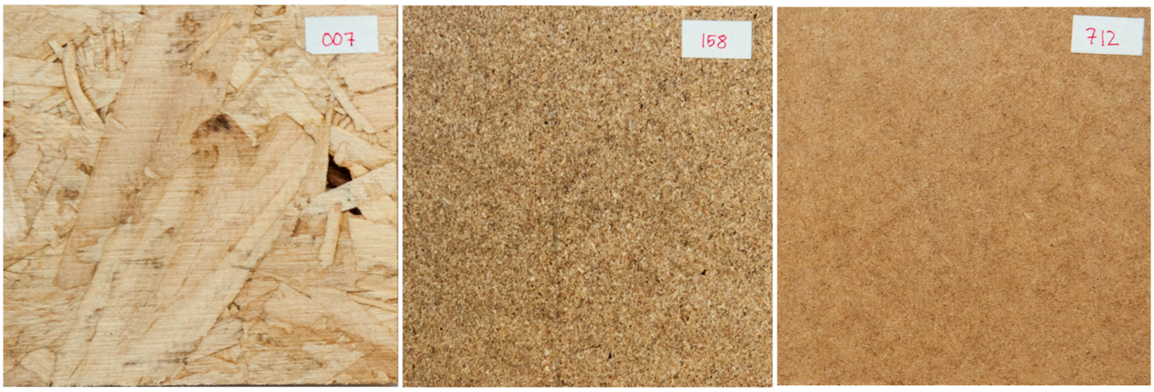


Figure 31: Three wood-based composites, each with greater degrees of transformation from their original state. From left: OSB, particleboard, MDF.

Anatomical features, such as knots in wood, may also contribute to perceptions of material naturalness similarly to apparent transformation. Although, the rough, clear pine specimen was rated as the most natural overall and ranked as the most natural by all groups except Norway, the planed, knotty pine specimen was ranked above the planed, clear specimen. Knots interrupt the pattern of recognizable anatomical features in wood elements (e.g., grain pattern, rays, and figure) and are considered a defect structurally (knots reduce the mechanical properties of wood), however the consistency of perceptions towards the pine specimen with knots may indicate that the interruption in the naturally occurring grain pattern is symbol of its authenticity as a natural material.

Although the initial expectation was to discover clear differences in perceptions of naturalness between countries and between Koper and Ljubljana in Slovenia, this prediction was not reflected in the results. The differences between country groups were minor by all measures, with strong statistical evidence for differences between the ratings of only two materials: Respondents from Finland rated particleboard as less natural than did Slovenian respondents and Norwegian respondents rated the WPC sample with imitated growth rings lower than did Slovenian respondents. There were no significant differences between Slovenian respondents in Koper and Ljubljana. The differences detected seemed indicative of a knowledge gap related to familiarity with wood products rather than culturally different attitudes and perceptions of material naturalness.

Solid wood, stone and brick tile were considered to be natural, while the items with greater degrees of processing were consistently regarded as being unnatural (e.g., steel, plastic, ceramics). The general agreement between each of the three measurement methods also provides a degree of self-validation of the results, which is important in this case because naturalness is not a precisely defined concept (Overvliet and Soto-Faraco 2011). Therefore, it is clear that users understood the task and performed it accurately (with the possible exception of the ranking task).

Indeed, it was clear that respondent perceptions of naturalness were consistent when considering materials they clearly believed to be natural and those they did not (e.g., solid wood and steel, respectively). However, there seemed to be more ambiguity in their responses to materials they considered to have moderate naturalness, such as particleboard, MDF, and WPCs. Overall, OSB was rated as more natural than other composites (mean: 5.02; 95% CI: 4.81-5.23) and was ranked higher as well (tied at 6.5 with brick). The larger, more recognizable, wood components visible in OSB may have contributed to its perception as highly natural.

As architects and building designers make material decisions, particularly when their goal is to reflect experiences of nature, life, and life-like processes, user perceptions of building material naturalness should be considered. The apparent number of transformations and quantity of additives may be more important than the actual transformations and additives present in a material. However, using materials closer to their raw state will likely ensure they are recognized as more natural than their heavily processed counterparts. The implications of material naturalness may also appear as designers implement restorative environmental design or regenerative design. In these cases, material naturalness may have direct impacts on human health, worker productivity, and learning.

To maximize the positive impacts on building occupant's future research should attempt to determine the source of restorative effects in the built environment and identify the most suitable design solutions for implementing them. Experiments must consider how design and materials impact occupant responses to stress, stress recovery, attention restoration, and other indicators of well-being. Focusing on occupant responses to materials and how they are used in the built environment in these studies will provide designers with a stronger foundation for designing healthy environments and provide society with healthier buildings. Furthermore, replicating this study in other locations and focusing on subsets of material classes (e.g., wood) with more variety within the class will further illuminate trends in people's perceptions of building material naturalness.

5.2 Human stress and stress recovery in office-like environments

Understanding psychophysiological stress and monitoring stress responses in office-like environments is a challenging yet critical area of study. It is necessary to provide robust evidence of positive human health impacts of building design decisions in order to create buildings that improve human health. In this study, the effect being examined is expected to be small and very between individuals. An experimental test method was developed to monitor stress responses and recovery, which was successful in observing and quantifying this phenomenon. Salivary free cortisol was the indicator of stress, and there were statistically significant differences between the control environment and the oak furniture (treated) environment. This preliminary evidence of a relationship between material selection and stress responses provides a foundation for future research delving into the relationship between building design and stress management in the workplace.

The conditions in the treated oak environment that may have been responsible for the improved stress response are more difficult to discern. Material naturalness, colour, luminance (a result of lighting level and material properties), and other attributes of the test environments varied along with the material type of the treated environment making it impossible to attribute any affect to a specific characteristic of the material (for example, grain pattern). However, the quantity of visible materials, temperature and relative humidity in the room, furniture design, seating, and experimental procedures were controlled for all tests. Therefore, the detected differences are likely to be associated the conditions in the room that varied, which were all related to the material selection for the visible furniture.

5.2.1 Methodological challenges

Although the method proved successful in observing and quantifying stress reactions in the experiment, adjustments to the protocol will provide even more useful information for future research. Due to the uncertain boundaries of the response period – that is, the varying and unknown amount of time between when the stressor occurs and when the cortisol response is observable in saliva and when the cortisol levels return to pre-stressor levels, the experiment protocol would have benefited from taking more measurements later in the test period. Following the current protocol, confidently identifying the peak response was difficult because it may have occurred between measurement intervals of the test in many cases. Another adjustment that would improve test outcomes would be extending the test duration. This adjustment would provide more insight into the recovery portion of the response period. In the current experiment, peak observed cortisol concentration occurred at the final reading in some cases, meaning no recovery from the peak stress state could be observed in those cases. In future experiments, lengthening the test period to 90 minutes and collecting more frequenting measurements during the response and recovery period is recommended (Figure 32). This adjustment will allow researchers to quantify the stress response more precisely. Eight samples are convenient for the salivary cortisol immune assay as well, allowing a complete set of samples from a single session to fill a column of a microtitre tray.

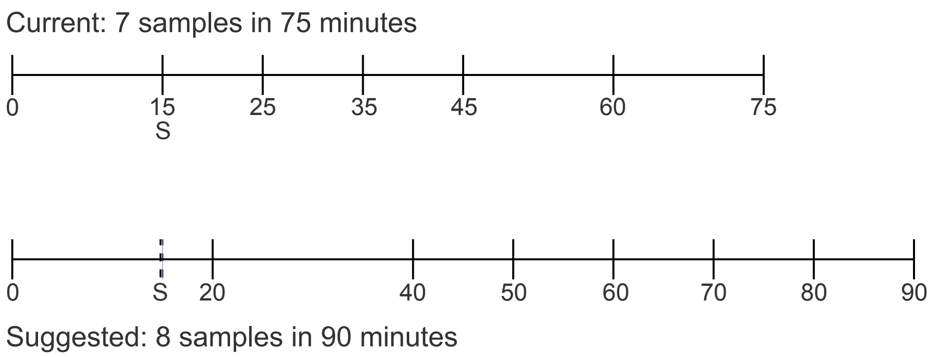


Figure 32: Recommended protocol adjustment for the duration and timing of sample collection and stressor. S=Stressor.

In addition to adjusting the timing and number of cortisol samples collected, using other indicators to observe reactions to the test environment such as heart rate variability (cf. Delaney and Brodie 2000), galvanic skin response, blood pressure (cf. Fernandes et al. 2014), or other non-invasive measures will increase the available knowledge about stress recovery in building while maintaining the viability of increasing the number of studies with adequate sample sizes, and experimental design.

Beyond physiological or biological indicators, monitoring and analysing neurological indicators will provide another level of understanding to help define the parameters of the built environment that improve stress reactions. Electroencephelograms (EEG) is a non-invasive method of measuring many neurological indicators, that have been demonstrated to reliably observe and quantify reactions to stress (Alonso et al. 2015).

These measures (and others) provide indications of how stress an individual becomes, and allows monitoring their recovery from stress, but do not provide information about performance under stress. Cognitive tasks have previously been used to compare performance under different environmental conditions and provide useful insight into how environments and stress impact human performance (e.g., Baron, Rea, and Daniels 1992; Ljungberg and Neely 2007).

With a broader range of measures, the degree of invasiveness felt by the test subject often increases. This may result in altered state or performance simply through the presence of the monitoring equipment. Likewise, excessive monitoring equipment may also reduce the restorative properties of the environment – the very aspect of the environment being tested. As an intermediary step before further larger studies, a series of studies exploring the most effective combination of metrics to inform practical building design decisions should be conducted.

5.2.2 From research to implementation

A long-term goal of this research area is to guide designers towards creating health-positive buildings by using natural materials for a variety of functional building components, should the evidence substantiate it. In this case, the results indicate using wood furniture can have a positive influence on reactions to stress in offices. Although the experiment was in a controlled laboratory setting, this evidence and previous research in the field (e.g., Fell 2010; Ikei, Song, and Miyazaki 2017), strengthen the call to begin utilising wood to provide health benefits to building occupants.

However, it is imperative any guidance provided to designers is evidence-based. Evidence-based design is well known in hospital and medical care facilities design, but has only slowly expanded outside that area (Zimmerman 2009). Cultural barriers may be one cause for the slow transition according to Zimmerman (2009). However, building rating systems (and the requirements of governments that new buildings be constructed to meet certain levels within rating systems) now provide a more familiar system for connecting evidence with design. It is the responsibility of researchers in this field to ensure results are meaningfully shared with rating systems agencies, and to designers through a variety of means.

A key consideration and open question in exploring and defining positive human health impacts in the built environment is the inflection point between limiting negative impacts and creating positive impacts. In a practical sense, the actions taken to achieve either limited harm or positive impact may not be strictly related. Design decisions taken to reduce the presence of harmful VOCs in a building are not necessarily related to a design decision to use oak furniture in place of non-wood furniture. From this perspective, including both aspects (eliminating sources of harm in the built environment and providing sources of positive health outcomes) should be considered on separate scales in any building design paradigm or rating system.

These design paradigms show continual growth in the treatment of nature and naturalness in building design. However, in all cases, access to more evidence of the various effects is needed to inform design decision. Furthermore, documentation on how to properly use materials in to achieve positive effects must be produced and widely disseminated. In addition to conducting and reporting research, scientists, designers, material and product manufacturers, users, and other stakeholders must come together and develop design strategies and documentation that create positive human health impacts.

As more evidence is collected and design paradigms more carefully crafted, several points should be considered about using wood to create positive human health impacts in the built environment:

1. While positive human health impacts are the goal, steps to mitigate harm must still be taken. Wood is susceptible to damage and mould problems when not properly installed or maintained.
2. User perceptions of their environment and of the source of stress are important issues to consider when designing to limit stress related responses. Materials play a role in how the environment is perceived, but so do many other aspects of design such as lighting, views of nature, and thermal comfort.
3. Simply replacing other materials with wood is not a definite solution. Using the material and making design choices to improve other aspects of human health is important as well.
4. Ergonomic interventions that reduce sedentary time, promote activity, provide accessibility, and safety are very important as well. These interventions can often be achieved using wood.
5. Social interaction in the building remains important.
6. Designing for environmental, economic, and societal benefits through broader regenerative or restorative design paradigms should not be overlooked.
7. Environmental interventions, like using wood as a visible material in buildings, when combined with therapeutic and social interventions are likely to improve human well-being in and out of the work place.

Design paradigms like regenerative design (Mang and Reed 2012) and restorative environmental design (Derr and Kellert 2013) offer broad frameworks and goals for building on social, environmental, economic, and cultural levels but have limited specific design guidelines. Building rating systems such as the Living Building Challenge (International Living Future Institute 2016) or the Well Building Standard (International Well Building Institute 2017) offer practical metrics for some of these aspects, but provide less guidance on how they should be implemented. Conceptual approaches to design, like biophilic design (Kellert 2008) are mentioned in both building rating systems listed above, and there are more specific guidelines for implementing this design concept. However, these guidelines are based on theoretical frameworks (e.g., biophilia, attention restoration theory, psychophysiological restoration theory) and only limited evidence. The scope of any design system or paradigm to capture all elements of the regenerative or restorative principles is incredibly large. An alternative to a broadly sweeping design system is to have targeted design guidelines for more specific aspects of designing healthy buildings. Restorative environmental and ergonomic design (REED) is one such approach. This design paradigm is focused renewable material use in building to create positive human health, environmental, and societal outcomes (Burnard, Schwarzkopf, and Kutnar 2016; Burnard 2017). Though currently under development, targeted research into the human benefits of using renewable materials in buildings are products will underpin the guidelines it provides.

5.2.3 Future research work on human health, wood, and the built environment

The two most critical aspects of future research working connecting human health outcomes to the use of wood in the built environment are: expanded health targets and replication. Expanding health targets to include, amongst other topics, musculoskeletal health, respiratory health, cognitive capacity, mental health, and social well-being by designing and administering experiments that use a variety of objective quantification methods is necessary to understand the scope of the effect design decisions have on occupant well-being. Like other research, especially that conducted in an emerging field, replication is critically important. Spurious results have the potential to cause harm in the health domain, making replication even more important.

On interdisciplinary research merging human health, materials science, engineering, and design

To appropriately expand and replicate results in this research area, combining expertise from a variety of disciplines is necessary. Health researchers with expertise from the mental health, physiology, neurology, endocrinology, and kinesiology domains, amongst others should be directly involved in planning and implementing the research activities that may eventually be used to determine guidelines on building design. Likewise, material scientists and engineers should be involved in developing targeted solutions for using natural materials in buildings that meet the requirements of preventing harm and creating the functionality required for building use. Finally, designers should be involved as well, to ensure the test environments used in the research reflect solutions that may be used in buildings (from both aesthetic design and regulations perspectives).

6 SUMMARY

6.1 Summary in English

Most humans now spend most of their time indoors making the built indoor environment critical to maintaining and enhancing human wellbeing (Ulrich 1991; S. Kaplan 1995; USGBC 2011). Humans are affected by many aspects of their surrounding environment. Building design choices including material selection, ventilation, lighting, amongst others, and are therefore important to occupant health (Ulrich 1991). Decisions surrounding these aspects of a building should be made to create positive impacts for building users, not only to mitigate harm.

One strategy to enhance occupant health in the built environment is to attempt to bring the natural environment indoors. Therefore, the studies presented here investigated the impact of wood use in building interiors on human stress, with a particular emphasis on improving stress responses and stress recovery in offices that could lead to improved productivity at the work place. Building occupants are impacted by their environment physically and psychosocially (Dolan, Foy, and Smith 2016). Their perceptions of their environment and the materials in it are based on visual recognition, haptic response, scents, and other sensory inputs (Bhatta and Kyttä 2016; Burnard et al. 2017; Burnard 2017). A literature review was conducted to identify the state of the art in this area of research, to identify weaknesses in previous studies, and identify the necessary experiments and methodology to advance the field. The literature review indicated the biophilia hypothesis, the attention restoration theory, and the psychophysiological restoration theory were useful theoretical frameworks for understanding how wood use could lead to improved health outcomes for building occupants. These frameworks state the innate human tendency to connect to life and life-like processes through interactions with nature lead to improved health outcomes, particularly related to stress and the ability to recovery attention deficits which may lead to improved work performance. The tenets of biophilia are implemented in building design through biophilic design, which suggests including natural elements into the built environment will lead to improved health outcomes for building users, and it is therefore important for users to perceive their environment as natural (Wilson 1984; Kellert and Wilson 1993; Kellert 2008). Understanding how building users perceive the naturalness of building materials was therefore critical to understand how to use wood and other natural materials to improve health outcomes in building interiors.

Building material naturalness was examined by administering a survey in Norway, Finland, and Slovenia which asked respondents to rate the naturalness of 22 building materials on three scales. Building material samples were presented to respondents for visual inspection of their surfaces to reflect how they would likely appear in the built environment. This study tested the hypothesis that wood would be considered to have high naturalness and that respondents in all three countries would concur. Additionally, the relationship between perceived naturalness and the degree of transformation building materials undergo was examined. Solid wood products were considered the most natural by all respondents, regardless of country, followed by stone. Materials having undergone greater degrees of transformation were considered less natural. For example, MDF was considered less natural than particleboard, which was considered less natural than OSB.

The literature review also revealed it was necessary to re-examine previous experiments using more robust experimental design and that endocrine responses to stress would be a robust, objective indicator of stress levels. Human stress responses would be examined in an experiment using robust methodology (within-subjects design) and salivary cortisol as the primary indicator of human stress response.

Accordingly, a study of human stress responses was conducted to compare stress responses in offices with wood furniture to stress responses in offices with non-wood furniture. Two types of wood furniture were compared to plain white control furniture: oak, a light-coloured wood with clearly visible grain pattern; and, walnut, a dark-coloured wood with noticeable, yet not as pronounced grain patterns. The plain white furniture was the control environment for a within-subjects experiment that monitored reactions to and recovery from an emotion induction stress procedure using salivary free cortisol as the primary indicator of stress level over a 75-minute period. Results indicate the oak furniture test environment produced statistically significant lower stress responses compared to the control environment, indicating environmental interventions may lead to reduced stress levels in offices. However, no significant differences were found between the walnut office and its corresponding control office, indicating the characteristics of wood that lead to reduced stress are important to study. No significant differences were found in the magnitude of the stress response or stress recovery for either type of wood furniture. Future studies should lengthen the test duration to allow more time for the response and recovery to become evident in salivary free cortisol, and more saliva samples should be collected in during the response and recovery periods of the experiment. These modifications to the experiment will provide greater fidelity in stress readings when they are most critical to characterise and compare stress responses between test environments.

There are many considerations to using wood in buildings to enhance human health outcomes. The studies presented provide further evidence that wood has the potential to improve human stress outcomes when used as a visible element in building interiors. Although further experimentation must be done to confirm and expand the findings of the human stress study, several key aspects of wood use as an environmental intervention to increase human health outcomes are apparent:

1. While positive human health impacts are the goal, steps to mitigate harm must still be taken. Wood is susceptible to damage and mould problems when not properly installed or maintained.

2. User perceptions of their environment and of the source of stress are important issues to consider when designing to limit stress related responses. Materials play a role in how the environment is perceived, but so do many other aspects of design such as lighting, views of nature, and thermal comfort.
3. Simply replacing other materials with wood is not a definite solution. Using the material and making design choices to improve other aspects of human health is important as well.
4. Ergonomic interventions that reduce sedentary time, promote activity, provide accessibility, and safety are very important as well. These interventions can often be achieved using wood.
5. Social interaction in the building remains important.
6. Designing for environmental, economic, and societal benefits through broader regenerative or restorative design paradigms should not be overlooked.
7. Environmental interventions, like using wood as a visible material in buildings, when combined with therapeutic and social interventions are likely to improve human well-being in and out of the work place.

To appropriately extend research and development activities related to human health and building interiors, combining expertise from a variety of disciplines is necessary. Health researchers with expertise from the mental health, physiology, neurology, endocrinology, and kinesiology domains, amongst others should be directly involved in planning and implementing the research activities that may eventually be used to determine guidelines on building with wood. Likewise, material scientists and engineers should be involved in developing targeted solutions for using natural materials in buildings that meet the requirements of preventing harm and creating the functionality required for building use. Finally, designers should be involved as well, to ensure the test environments used in the research reflect solutions that may be used in buildings (from both aesthetic design and regulations perspectives).

The two most critical aspects of future research working on connecting human health outcomes to the use of wood in the built environment are: expanded health targets and replication. Expanding health targets beyond stress to include, amongst other topics, musculoskeletal health, respiratory health, cognitive capacity, mental health, and social well-being by designing and administering experiments that use a variety of objective quantification methods is necessary to understand the scope of the effect design decisions have on occupant well-being. Like other research, especially that conducted in an emerging field, replication is critically important. Spurious results have the potential to cause harm in the health domain, making replication even more important.

6.2 Summary in Slovene

Dandanes ljudje večino svojega časa preživimo v notranjih prostorih, zaradi česar ima notranje grajeno okolje bistveno vlogo pri ohranjanju in spodbujanju blagostanja uporabnikov (Ulrich 1991; S. Kaplan 1995; USGBC 2011). Ljudje smo podvrženi vplivom različnih vidikov našega okolja. Odločitve pri zasnovi zgradb med drugim vključujejo izbiro materialov, prezračevanja in razsvetljave, zaradi česar so pomembne za zdravje ljudi (Ulrich 1991). Odločitve okrog teh vidikov zgradb bi morale uporabnikom zgradb zagotavljati koristi v smislu pozitivnih učinkov, ne zgolj zmanjševanja škode.

Ena od strategij za spodbujanje zdravja uporabnikov grajenega okolja vključuje prenos naravnih okolij v notranje prostore. Raziskave, ki so tu predstavljene, so tako preučevale učinek rabe lesa v notranjosti stavb na stres ljudi, s posebnim poudarkom na izboljšanju stresnega odziva in okrevanja od stresa v pisarnah, kar bi lahko vodilo k izboljšani produktivnosti na delovnem mestu. Vplivi, ki jih ima okolje na uporabnike stavb, so tako fizični kot psihosocialni (Dolan, Foy in Smith 2016). Ti uporabniki percepcije svojega okolja in materialov v njem osnujejo na podlagi vidnih prepoznav, haptičnega odziva, vonjev in preko drugih senzoričnih poti (Bhatta in Kyttä 2016; Burnard idr. 2017; Burnard 2017). Da bi prepoznali najsodobnejše znanje na tem področju raziskovanja, prepoznali pomanjkljivosti predhodnih raziskav ter ugotovili, kateri eksperimenti in metodologija bi bili potrebni za napredovanje področja, smo izvedli pregled literature. Pregled literature je prepoznal biofilično hipotezo, teorijo restoracije pozornosti in teorijo psihofiziološkega okrevanja kot uporabne teoretske okvire za razumevanje, kako bi uporaba lesa v grajenem okolju lahko vodila do izboljšanja zdravja uporabnikov zgradb. Ti okviri postavljajo tezo, da človekova intrinzična težnja po povezovanju z življenjem in z njim povezanimi procesi preko interakcije z naravo vodi k izboljšanju zdravja in blagostanja. Slednje je povezano predvsem s stresom in okrevanjem izčrpanih sposobnosti za usmerjanje pozornosti, kar lahko vodi k izboljšanju učinkovitosti pri delu. Ključni elementi biofilije so v zasnovo zgradb vključeni prek biofiličnega dizajna, ki predpostavlja, da bo vključevanje elementov narave v grajeno okolje vodilo do izboljšanih zdravstvenih rezultatov za uporabnike taistih zgradb, zaradi česar je pomembno, da uporabniki svoje okolje zaznavajo kot naravno (Wilson 1984; Kellert in Wilson 1993; Kellert 2008). Razumevanje, kako uporabniki zgradb zaznavajo naravnost gradbenih materialov, je bilo torej bistvenega pomena za spoznavanje načinov rabe lesa in drugih naravnih materialov za izboljšanje zdravja ljudi v notranjosti stavb.

Naravnost gradbenih materialov je bila preučevana s pomočjo ankete, izvedene na Norveškem, Finskem in v Sloveniji. V anketi so udeleženci na treh lestvicah ocenjevali naravnost 22 različnih gradbenih materialov. Udeleženci so si lahko ogledali površine vzorcev materialov, kar odraža stik, v kakršnem bi bili z materiali v grajenem okolju. Študija je preizkušala hipotezo, da bo les ocenjen z visoko stopnjo naravnosti in da se bo to pokazalo v vseh treh državah. Preučena je bila tudi povezava med ocenjeno naravnostjo in stopnjo predelanosti gradbenih materialov. Izdelke iz masivnega les so vsi udeleženci ne glede na državo ocenili kot najbolj naravne, temu je sledil kamen. Materiali, ki so bili podvrženi višji stopnji obdelave, so bili ocenjeni kot manj naravni. Plošča MDF je bila denimo ocenjena kot manj naravna od iverne plošče, ki je bila ponovno ocenjena kot manj naravna v primerjavi s ploščo OSB.

Pregled literature je nakazal tudi potrebo po ponovitvi predhodnih eksperimentov z bolj robustno eksperimentalno zasnovo ter da bi v tem primeru endokrini odzivi na stres bili robusten in objektiven kazalnik ravni stresa. Stresni odzivi ljudi bi tako bili preučeni v okviru eksperimenta z robustno metodologijo (zasnova s ponovljenim merjenjem) in z uporabo kortizola v slini kot osrednjim kazalnikom stresnega odziva ljudi.

Tem ugotovitvam je sledila raziskava na temo stresnega odziva ljudi, ki je primerjala stresne odzive v pisarnah z lesenim pohištvom in v pisarnah, v katerih pohištvo ni bilo leseno. Z belim pohištvom, ki je služilo kot kontrola, sta bila primerjana dva tipa lesenega pohištva: hrast, svetel les z izrazito teksturo; in oreh, temen les z opazno, a ne tako izrazito teksturo. Belo pohištvo je bilo kontrolno okolje eksperimenta s ponovljenim merjenjem, ki je s pomočjo izmerjenega prostega kortizola v slini kot osrednjega kazalnika ravni stresa spremljal reakcijo na in okrevanje od stresnega dogodka v obdobju 75 minut. Rezultati kažejo, da je testno okolje s hrastovim pohištvom pripomoglo k blažjim stresnim odzivom udeležencev v primerjavi s kontrolnim okoljem, ta razlika pa je statistično značilna. Ti rezultati kažejo, da lahko okoljske intervencije vodijo do zmanjšanih ravni stresa v pisarnah. Nobene značilne razlike pa se niso pojavile med pisarno s pohištvom iz oreha in pripadajočo kontrolno pisarno, nakazujoč da so značilnosti lesa, ki vplivajo na ravni stresa, pomemben predmet raziskav. Prav tako ni bilo moč opaziti značilnih razlik v jakosti stresnega odziva ali okrevanja od stresa pri obeh vrstah lesenega pohištva. Prihodnje raziskave bi morale podaljšati trajanje poskusov, kar bi dopustilo več časa, da se odziv in okrevanje od stresa pokažeta v ravneh kortizola v slini, prav tako pa bi bilo potrebno zajeti več vzorcev sline tekom obdobij stresnega odziva in okrevanja v eksperimentu. Te spremembe v metodologiji bi omogočile zajem natančnejših podatkov o ravni stresa v obdobjih, ki so največjega pomena za opredelitev in primerjavo stresnih odzivov med testnimi okolji.

Veliko vidikov podpira uporabo lesa v stavbah z namenom spodbujanja zdravja pri ljudeh. Predstavljene raziskave služijo kot dodatni dokazi, da les poseduje potencial za lajšanje stresa pri ljudeh, ko je uporabljen kot viden element v notranjosti stavb. Čeprav je prihodnje potrebno nadaljevati z eksperimenti, da bi potrdili in razširili ugotovitve študije na temo stresa pri ljudeh, je na tej točki več vidikov rabe lesa kot okoljske intervencije za izboljšanje zdravja ljudi očitnih:

1. Pozitivni učinki na zdravje ljudi so cilj, vendar je potrebno ohranjati ukrepe za zmanjševanje škode. Les je dovzeten za poškodbe in težave s plesnijo, ko ni pravilno vgrajen in vzdrževan.

2. Percepcije uporabnikov o svojih okoljih in virih stresa je potrebno upoštevati, ko oblikujemo zgradbo z željo omejevanja stresnih odzivov. Materiali igrajo pomembno vlogo v tem, kako je okolje zaznano, vendar so v ta proces vključeni še elementi dizajna, kot so razsvetljava, pogledi na naravo in toplotno udobje.
3. Zamenjava drugih materialov z lesom ni dokončna rešitev. Raba materiala in sprejemanje odločitev o dizajnu z namenom izboljšanja drugih vidikov zdravja ljudi sta prav tako pomembna.
4. Ergonomske intervencije, katerih cilj je krajšanje časa v sedečem položaju, promocija telesne aktivnosti, zagotavljanje dostopnosti in varnosti, so tudi zelo pomembne. Te intervencije je pogosto moč doseči z uporabo lesa.
5. Socialne interakcije v stavbi ostajajo pomemben vidik dizajna.
6. Oblikovanja zgradb za okoljske, ekonomske in družbene koristi preko paradigem regenerativnega oziroma restorativnega dizajna ne gre spregledati.
7. Združevanje okoljskih intervencij, kot je raba lesa kot vidnega materiala v stavbah, in terapevtskih ter socialnih intervencij lahko izboljša blagostanje ljudi na delovnih mestih in izven njih.

Da lahko korektno razširimo razvojno-raziskovalne dejavnosti, povezane z zdravjem ljudi in notranjostjo stavb, moramo združiti strokovno znanje več disciplin. Raziskovalci s področja zdravja ljudi z znanjem in izkušnjami s področij duševnega zdravja, fiziologije, nevrologije, endokrinologije, kineziologije in drugih domen bi morali biti neposredno vpeti v načrtovanje in implementiranje raziskovalnih dejavnosti, ki so sčasoma lahko temelj za določanje smernic glede gradnje z lesom. Prav tako bi morali znanstveniki in inženirji s področja materialov biti vključeni v razvoj ciljnih rešitev za uporabo naravnih materialov v stavbah, ki tako izpolnjujejo zahteve glede preprečevanja škode in funkcionalnosti, potrebne za uporabo stavbe. Nenazadnje bi v ta proces morali biti vpeti tudi strokovnjaki, ki sodelujejo pri oblikovanju stavbe. Ti bi zagotovili, da testna okolja, uporabljena v raziskavah, odražajo rešitve, ki so lahko uporabljene v stavbah (z vidikov estetike dizajna in omejitev s strani zakonodaje).

Najbolj kritična vidika prihodnjega raziskovalnega dela na področju povezovanja zdravja ljudi z uporabo lesa v grajenem okolju sta: širši ciljni vidiki zdravja in replikacija. Da bi razumeli obseg učinkov, ki jih ima dizajn na blagostanje uporabnikov, moramo razširiti ciljne vidike zdravja, da poleg stresa vključujejo še muskuloskeletno zdravje, respiratorno zdravje, kognitivne sposobnosti, duševno zdravje in socialno blagostanje. To bi dosegli s snovanjem in izvajanjem eksperimentov z raznovrstnimi objektivnimi metodami kvantifikacije, ki bi poglobili naše razumevanje učinkov, ki jih imajo odločitve o dizajnu stavb na blagostanje uporabnikov. Tako kot za ostale raziskave, posebno te na uveljavljajočih se področjih, je tudi za to replikacija izrednega pomena. Zmotni zaključki lahko povzročijo škodo na področju zdravja, zaradi česar je replikacija toliko večjega pomena.

REFERENCES

Alonso, J F, S Romero, M R Ballester, R M Antonijoan, and M A Mañanas. 2015. "Stress Assessment Based on EEG Univariate Features and Functional Connectivity Measures." *Physiological Measurement* 36 (7). IOP Publishing: 1351–65. doi:10.1088/0967-3334/36/7/1351.

Amerikanski Slovenec. 1934. "Amerikanski Slovenec."

Amundsen, Astrid H., Ronny Klæboe, and Gunn Marit Aasvang. 2011. "The Norwegian Façade Insulation Study: The Efficacy of Façade Insulation in Reducing Noise Annoyance due to Road Traffic." *The Journal of the Acoustical Society of America* 129 (3): 1381–89. doi:10.1121/1.3533740.

Asdrubali, Francesco. 2006. "Survey on The Acoustical Properties of New Sustainable Materials for Noise Control." In *Proceedings of Euronoise 2006*, 1–10. Tampere, Finland. http://www.ciriaf.it/ft/File/Pubblicazioni/pdf/1279.pdf.

Attaianese, Erminia, and Gabriella Duca. 2012. "Human Factors and Ergonomic Principles in Building Design for Life and Work Activities: An Applied Methodology." *Theoretical Issues in Ergonomics Science* 13 (2): 187–202. doi:10.1080/1463922X.2010.504286.

Baron, Robert A, Mark S Rea, and Susan G Daniels. 1992. "Effects of Indoor Lighting (Illuminance and Spectral Distribution) on the Performance of Cognitive Tasks and Interpersonal Behaviors: The Potential Mediating Role of Positive Affect." *Motivation and Emotion* 16 (1): 1–33. doi:10.1007/BF00996485.

Bernadet, P. 1995. "Benefits of Physical Activity in the Prevention of Cardiovascular Diseases." *Journal of Cardiovascular Pharmacology* 25 Suppl 1. United States: S3-8.

Bhatta, Shiv, and Marketta Kyttä. 2016. "Sensory Experiences of Wood: Achieving The Energy Efficiency and User Satisfaction." In *Functional Wood*, edited by Yrsa Cronhjort, Mark Hughes, Karola Sahi, and Pekka Tukiainen, 96–99. Helsinki: Aalto University. https://aaltodoc.aalto.fi/handle/123456789/21531.

Bringslimark, Tina, Terry Hartig, and Grete G. Patil. 2009. "The Psychological Benefits of Indoor Plants: A Critical Review of the Experimental Literature." *Journal of Environmental Psychology* 29 (4). Elsevier Ltd: 422–33. doi:10.1016/j.jenvp.2009.05.001.

Bulian, Franco, and Cristiano Fragassa. 2016. "VOC Emissions From Wood Products and Furniture: A Survey About Legislation, Standards and Measures Referred to Different Materials." *FME Transactions* 44 (4): 359.

Burchfield, S R. 1979. "The Stress Response: A New Perspective." *Psychosomatic Medicine* 41 (8): 661–72.

Burnard, Michael. 2017. "Bio-Based Materials and Human Well-Being in the Built Environment." In *Performance of Bio-Based Materials*, edited by Dennis Jones and Christian Brischke, 1st ed., 365–72. Duxford: Woodhead Publishing.

Burnard, Michael, and Andreja Kutnar. 2015. "Wood and Human Stress in the Built Indoor Environment: A Review." *Wood Science and Technology* 49 (5). Springer Berlin Heidelberg: 969–86. doi:10.1007/s00226-015-0747-3.

Burnard, Michael, Anders Q. Nyrud, Kristian Bysheim, Andreja Kutnar, Katja Vahtikari, and Mark Hughes. 2017. "Building Material Naturalness: Perceptions from Finland, Norway and Slovenia." *Indoor and Built Environment* 26 (1): 92–107. doi:10.1177/1420326X15605162.

Burnard, Michael, Matthew Schwarzkopf, and Andreja Kutnar. 2016. "Interdisciplinary Approaches to Developing Wood Modification Processes for Sustainable Building and beyond – INNORENEW COE." In *Proceedings of the World Conference on Timber Engineering*. Vienna: Technical University of Vienna.

Chrousos, G. P., and P.W. Gold. 1998. "A Healthy Body in a Healthy Mind--and Vice Versa--The Damaging Power of 'Uncontrollable' Stress." *Journal of Clinical Endocrinology & Metabolism* 83 (6): 1842–45. doi:10.1210/jc.83.6.1842.

Cohen, Sheldon, Ronald Kessler, and Lynn Underwood-Gordon. 1995. *Measuring Stress: A Guide for Health and Social Scientists*. New York: Oxford University Press.

Danna, Karen, and Ricky W. Griffin. 1999. "Health and Well-Being in the Workplace: A Review and Synthesis of the Literature." *Journal of Management* 25 (3): 357–84. doi:10.1177/014920639902500305.

Delaney, J. P. A., and D. A. Brodie. 2000. "Effects of Short-Term Psychological Stress on the Time and Frequency Domains of Heart-Rate Variability." *Perceptual and Motor Skills* 91 (2): 515–24. doi:10.2466/pms.2000.91.2.515.

Derr, Victoria, and Stephen R Kellert. 2013. "Making Children's environments 'R.E.D.': Restorative Environmental Design and Its Relationship to Sustainable Design." In *Proceedings of the 44th Annual Conference of the Environmental Design Research Association.*, edited by E Pavlides and J Wells.

Dickerson, Sally S, and Margaret E Kemeny. 2004. "Acute Stressors and Cortisol Responses: A Theoretical Integration and Synthesis of Laboratory Research." *Psychological Bulletin* 130 (3): 355–91. doi:10.1037/0033-2909.130.3.355.

Dolan, Paul, Chloe Foy, and Sophie Smith. 2016. "The SALIENT Checklist: Gathering up the Ways in Which Built Environments Affect What We Do and How We Feel." *Buildings* 6 (1): 9. doi:10.3390/buildings6010009.

Dressendörfer, R.A., C. Kirschbaum, W. Rohde, F. Stahl, and C.J. Strasburger. 1992. "Synthesis of a Cortisol-Biotin Conjugate and Evaluation as a Tracer in an Immunoassay for Salivary Cortisol Measurement." *The Journal of Steroid Biochemistry and Molecular Biology* 43 (7): 683–92. doi:10.1016/0960-0760(92)90294-S.

Dul, Jan, Ralph Bruder, Peter Buckle, Pascale Carayon, Pierre Falzon, William S Marras, John R Wilson, and Bas van der Doelen. 2012. "A Strategy for Human Factors/ergonomics: Developing the Discipline and Profession." *Ergonomics* 55 (4): 377–95. doi:10.1080/00140139.2012.661087.

Environmental Protection Agency (EPA). 2016. "Formaldehyde Emissions Standards for Composite Wood Products. Docket Numbers: EPA-HQ-OPPT-2012-0018, EPA-HQ-OPPT-2011-0380."

European Comission. 1992. *EN 120:1992 - Wood Based Panels. Determination of Formaldehyde Content. Extraction Method Called the Perforator Method.*

FAO. 2010. "Global Forest Resources Assessment 2010." *FAO Forestry Paper*. Vol. 163. Rome.

Fell, David. 2010. "Wood In the Human Environment: Restorative Properties of Wood in the Built Indoor Environment." University of British Columbia.

Fernandes, Atlee, Rakesh Helawar, R Lokesh, Tushar Tari, and Ashwini V Shahapurkar. 2014. "Determination of Stress Using Blood Pressure and Galvanic Skin Response." *Communication and Network Technologies (ICCNT), 2014 International*, 165–68. doi:10.1109/CNT.2014.7062747.

Finnegan, M J, C A Pickering, and P S Burge. 1984. "The Sick Building Syndrome: Prevalence Studies." *British Medical Journal (Clinical Research Ed.)* 289 (6458): 1573–75. doi:http://dx.doi.org/10.1136/bmj.289.6458.1573.

Fleming, Roland W., Christiane Wiebel, and Karl Gegenfurtner. 2013. "Perceptual Qualities and Material Classes." *Journal of Vision* 13 (8): 9. doi:10.1167/13.8.9.

Gaab, J., N. Blättler, T. Menzi, B. Pabst, S. Stoyer, and U. Ehlert. 2003. "Randomized Controlled Evaluation of the Effects of Cognitive-Behavioral Stress Management on Cortisol Responses to Acute Stress in Healthy Subjects." *Psychoneuroendocrinology* 28 (6): 767–79. doi:10.1016/S0306-4530(02)00069-0.

Gallego, Eva, Xavier Roca, Jose Francisco Perales, and Xavier Guardino. 2009. "Determining Indoor Air Quality and Identifying the Origin of Odour Episodes in Indoor Environments." *Journal of Environmental Sciences* 21 (3). Elsevier: 333–39. doi:10.1016/S1001-0742(08)62273-1.

Graeven, David B. 1975. "Necessity, Control, and Predictability of Noise as Determinants of Noise Annoyance." *Journal of Social Psychology* 95 (1): 85–90. doi:10.1080/00224545.1975.9923237.

Greengrass, Paul. 2016. *Jason Bourne*. USA: Captivate Entertainment.

Gronwall, D. M. A. 1977. "Paced Auditory Serial-Addition Task: A Measure of Recovery from Concussion." *Perceptual and Motor Skills* 44 (2): 367–73. doi:10.2466/pms.1977.44.2.367.

Hameury, Stéphane, and Tor Lundström. 2004. "Contribution of Indoor Exposed Massive Wood to a Good Indoor Climate: In Situ Measurement Campaign." *Energy and Buildings* 36 (3): 281–92. doi:10.1016/j.enbuild.2003.12.003.

Hartig, Terry. 2004. "Toward Understanding the Restorative Environment as a Health Resource." *... : People Space. Engaging with the Environment. ...*.

Hartig, Terry, Gary W. Evans, Larry D. Jamner, Deborah S. Davis, and Tommy Gärling. 2003. “Tracking Restoration in Natural and Urban Field Settings.” *Journal of Environmental Psychology* 23 (2): 109–23. doi:10.1016/S0272-4944(02)00109-3.

Hartig, Terry, Kalevi Korpela, Gary W Evans, and Tommy Gärling. 1997. “A Measure of Restorative Quality in Environments.” *Scandinavian Housing and Planning Research* 14 (4). Taylor & Francis: 175–94. doi:10.1080/02815739708730435.

Hashimoto, S., M. Nose, T. Obara, and Y. Moriguchi. 2002. “Wood Products: Potential Carbon Sequestration and Impact on Net Carbon Emissions of Industrialized Countries.” *Environmental Science & Policy* 5 (2): 183–93. doi:10.1016/S1462-9011(01)00045-4.

Hellhammer, Dirk H., Stefan Wüst, and Brigitte M. Kudielka. 2009. “Salivary Cortisol as a Biomarker in Stress Research.” *Psychoneuroendocrinology* 34 (2): 163–71. doi:10.1016/j.psyneuen.2008.10.026.

Herzog, Thomas, Andrea Black, Kimberlee Fountain, and Deborah Knots. 1997. “Reflection and Attentional Recovery as Distinctive Benefits of Restorative Environments.” *Journal of Environmental Psychology* 17: 165–70.

Huang, Jian, and Kaichang Li. 2008. “A New Soy Flour-Based Adhesive for Making Interior Type II Plywood.” *JAOCS, Journal of the American Oil Chemists’ Society* 85 (1): 63–70. doi:10.1007/s11746-007-1162-1.

Ikei, Harumi, Chorong Song, and Yoshifumi Miyazaki. 2017. “Physiological Effects of Wood on Humans: A Review.” *Journal of Wood Science* 63 (1). Springer Japan: 1–23. doi:10.1007/s10086-016-1597-9.

International Living Future Institute. 2016. “Living Building Challege 3.1 : A Visionary Path to a Regenerative Future.” *Living Future Institute*. Vol. 31. Seattle. https://living-future.org/sites/default/files/16-0504 LBC 3_1_v03-web.pdf.

International Well Building Institute. 2017. “The Well Building Standard.” New York.

ISO/IEC. 2005. “ISO 7730:2005 Ergonomics of the Thermal Environment -- Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria.”

ISO/IEC. 2006. “ISO/IEC 14040:2006 Environmental Management -- Life Cycle Assessment -- Principles and Framework.” http://www.iso.org/iso/catalogue_detail?csnumber=37456.

Jafarian, Hoda, Claude M.H. Demers, Pierre Blanchet, and Véronic Landry. 2016. “Impact of Indoor Use of Wood on the Quality of Interior Ambiances under Overcast and Clear Skies : Case Study.” *BioResources* 11 (2015): 1647–63. doi:10.15376/biores.11.1.1647-1663.

Jang, Yonghwan, Jian Huang, and Kaichang Li. 2011. “A New Formaldehyde-Free Wood Adhesive from Renewable Materials.” *International Journal of Adhesion and Adhesives* 31 (7). Elsevier: 754–59. doi:10.1016/j.ijadhadh.2011.07.003.

Jensen, Lilli Kirkeskov, Annelise Larsen, Lars M⊘lhave, Mogens Kragh Hansen, and Bodil Knudsen. 2001. “Health Evaluation of Volatile Organic Compound (VOC) Emissions from Wood and Wood-Based Materials." *Archives of Environmental Health: An International Journal* 56 (5). Routledge: 419–32. doi:10.1080/00039890109604477.

Jonsson, Ragnar. 2005. "The End Consumer's Choice of Floorcovering in the Netherlands and the United Kingdom: A Comparative Pilot Study of Substitute Competition." *Journal of Wood Science* 51 (2): 154–60. doi:10.1007/s10086-004-0632-4.

Jonsson, Ragnar 2006. "Increasing the Competitiveness of Wood in Material Substitution: A Method for Assessing and Prioritizing Customer Needs." *Journal of Wood Science* 52 (2): 154–62. doi:10.1007/s10086-005-0741-8.

Kaplan, Rachel, and Eugene J. Herbert. 1987. "Cultural and Sub-Cultural Comparisons in Preferences for Natural Settings." *Landscape and Urban Planning* 14: 281–93. doi:10.1016/0169-2046(87)90040-5.

Kaplan, Rachel, and Stephen Kaplan. 1989. "The Experience of Nature: A Psychological Perspective." *Cambridge University Press*, 6.

Kaplan, Stephen. 1995. "The Restorative Benefits of Nature: Toward an Integrative Framework." *Journal of Environmental Psychology* 15 (3): 169–82. doi:10.1016/0272-4944(95)90001-2.

Kellert, Stephen R. 2008. "Dimensions, Elements and Attributes of Biophilic Design." In *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life*, edited by Stephen R Kellert, JH Heerwagen, and ML Mador, 1st ed., 3–19. Hoboken: Wiley.

Kellert, Stephen R, and Edward O Wilson. 1993. *The Biophilia Hypothesis*. *Frontiers in Ecology and the Environment*. Vol. 5.

Kirschbaum, Clemens, and Dirk H. Hellhammer. 1994. "Salivary Cortisol in Psychoneuroendocrine Research: Recent Developments and Applications." *Psychoneuroendocrinology* 19 (4): 313–33. doi:10.1016/0306-4530(94)90013-2.

Kirschbaum, Clemens, Brigitte M Kudielka, Jens Gaab, Nicole C Schommer, and Dirk H Hellhammer. 1999. "Impact of Gender, Menstrual Cycle Phase, and Oral Contraceptives on the Activity of the Hypothalamic-Pituitary-Adrenal Axis." *Psychosomatic Medicine* 61 (2): 154–62. http://ezproxy.csusm.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=1999-10946-006&site=ehost-live.

Kirschbaum, Clemens, Karl-Martin Pirke, and Dirk H. Hellhammer. 1993. "The 'Trier Social Stress Test' – A Tool for Investigating Psychobiological Stress Responses in a Laboratory Setting." *Neuropsychobiology* 28 (1–2): 76–81. doi:10.1159/000119004.

Kirschbaum, Clemens, Jens Preussner, Arthur Stone, Ilona Federenko, Jens Gaab, Doris Lintz, Nicole Schommer, and Dirk H. Hellhammer. 1995. "Persistent High Cortisol Respnoses to Repeated Psychological Stress in a Subpopulation of Healthy Men." *Psychosomatic Medicine* 57: 468–74.

Kirschbaum, Clemens, Stefan Wüst, and Dirk H. Hellhammer. 1992. "Consistent Sex Differences in Cortisol Responses to Psychological Stress." *Psychosomatic Medicine* 54

(6): 648–57. doi:0033-3174/92/5406-0648J03 00/0.

Kjellberg, Anders, and Ulf Landström. 1994. "Noise in the Office: Part II — The Scientific Basis (Knowledge Base) for the Guide." *International Journal of Industrial Ergonomics* 14 (1–2): 93–118. doi:10.1016/0169-8141(94)90008-6.

Kraniotis, D, N Langouet, T Orskaug, K Nore, and G Glaso. 2016. "Moisture Buffering and Latent Heat Sorption Phenomena of a Wood-Based Insulating Sandwich Panel." In *Proceedings of the World Conference on Timber Engineering, August 22-25*. Vienna: Technical University of Vienna.

Ljungberg, Jessica K., and Gregory Neely. 2007. "Stress, Subjective Experience and Cognitive Performance during Exposure to Noise and Vibration." *Journal of Environmental Psychology* 27 (1): 44–54. doi:10.1016/j.jenvp.2006.12.003.

Lucini, Daniela, Guido Norbiato, Mario Clerici, and Massimo Pagani. 2002. "Hemodynamic and Autonomic Adjustments to Real Life Stress Conditions in Humans." *Hypertension* 39 (1): 184–88. doi:10.1161/hy0102.100784.

MacFarquhar, Larissa. 2011. "How to Be Good: An Oxford Philosopher Thinks He Can Distill All Morality into a Formula. Is He Right?" *New Yorker*, September. http://www.newyorker.com/magazine/2011/09/05/how-to-be-good.

Mang, Pamela, and Bill Reed. 2012. "Designing from Place: A Regenerative Framework and Methodology." *Building Research & Information* 40 (1): 23–38. doi:10.1080/09613218.2012.621341.

Manninen, Anne-Marja, Pertti Pasanen, and Jarmo K. Holopainen. 2002. "Comparing the VOC Emissions between Air-Dried and Heat-Treated Scots Pine Wood." *Atmospheric Environment* 36 (11): 1763–68. doi:10.1016/S1352-2310(02)00152-8.

Masuda, Minoru. 2004. "Why Wood Is Excellent for Interior Designing? From Vision Physical Point of View." *Proceedings of the 8th World Conference on Timber Engineering*, 101–6.

McCraty, Rollin, Mike Atkinson, Dana Tomasino, and Raymond Trevor Bradley. 2009. "The Coherent Heart: Heart-Brain Interactions, Psychophysiological Coherence, and the Emergence of System-Wide Order." *Integral Review* 5 (2): 10–115.

McEwen, Bruce S. 2008. "Central Effects of Stress Hormones in Health and Disease: Understanding the Protective and Damaging Effects of Stress and Stress Mediators." *European Journal of Pharmacology* 583 (2): 174–85. doi:https://doi.org/10.1016/j.ejphar.2007.11.071.

McEwen, Bruce S. 1998. "Protective and Damaging Effects of Stress Mediators." Edited by Jeffrey S. Flier and Lisa H. Underhill. *New England Journal of Medicine* 338 (3): 171–79. doi:10.1056/NEJM199801153380307.

Milota, Michael. 2000. "Emissions from Wood Drying." *Forest Products Journal* 50 (June): 10–20.

Milota, Michael, Paul Mosher, and Kaichang Li. 2007. "VOC and HAP Removal from Dryer Exhaust Gas by Absorption into Ionic Liquids." *Forest Products Journal* 57 (5): 73–77.

Nyrud, Anders Q., and Tina Bringslimark. 2010. "Is Interior Wood Use Psychologically Beneficial? A Review of Psychological Responses toward Wood." *Wood and Fiber Science* 42 (2): 202–18.

Nyrud, Anders Q., Kristian Bysheim, and Tina Bringslimark. 2010. "Health Benefits from Wood Interior in a Hospital Room." In *Proceedings of the International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe, Geneva, Switzerland*, 1114:Paper WS-56. Geneva: Society of Wood Science and Engineering and United Nations Economic Commission for Europe -- Timber committee.

Nyrud, Anders Q., CA Clementz, Y Steiner, K Bysheim, and Arnseth JH. 2010. "Correlation between Building Material Naturalness and Perception of Indoor Environments [Sammenhengen Mellom Byggematerialer Og Folks Opplevelser Av Innemiljø] Rapport 8." Oslo.

Nyrud, Anders Q, Tina Bringslimark, and Kristian Bysheim. 2013. "Benefits from Wood Interior in a Hospital Room: A Preference Study." *Architectural Science Review*, 1–7. doi:10.1080/00038628.2013.816933.

O'Connor, Jennifer, Robert Kozak, Christopher Gaston, and David Fell. 2004. "*Wood Use in Nonresidential Buildings: Opportunities and Barriers*." *Forest Products Journal* 54 (3): 19–28.

Overvliet, Krista E., and Salvador Soto-Faraco. 2011. "I Can't Believe This Isn't Wood! An Investigation in the Perception of Naturalness." *Acta Psychologica* 136 (1). Elsevier B.V.: 95–111. doi:10.1016/j.actpsy.2010.10.007.

Park, Bum-Jin, Yuko Tsunetsugu, Tamami Kasetani, Hideki Hirano, Takahide Kagawa, Masahiko Sato, and Yoshifumi Miyazaki. 2007. "Physiological Effects of Shinrin-Yoku (Taking in the Atmosphere of the Forest)--Using Salivary Cortisol and Cerebral Activity as Indicators." *Journal of Physiological Anthropology* 26 (2): 123–28. doi:JST.JSTAGE/jpa2/26.123 [pii].

Pedersen, Thomas Lin. 2016. "Ggforce: Accelerating 'ggplot2.'" https://cran.r-project.org/package=ggforce.

Pelletier, K R. 2001. "A Review and Analysis of the Clinical- and Cost-Effectiveness Studies of Comprehensive Health Promotion and Disease Management Programs at the Worksite: 1998-2000 Update." *American Journal of Health Promotion : AJHP* 16 (2). United States: 107–16.

Petrič, Marko. 2013. "Surface Modification of Wood." *Reviews of Adhesion and Adhesives* 1 (2): 216–47. doi:10.7569/RAA.2013.097308.

Plessis, Chrisna du. 2012. "Towards a Regenerative Paradigm for the Built Environment." *Building Research & Information* 40 (1): 7–22. doi:10.1080/09613218.2012.628548.

Raanaas, Ruth K., Katinka Horgen Evensen, Debra Rich, Gunn Sjøstrøm, and Grete Patil. 2011.

"Benefits of Indoor Plants on Attention Capacity in an Office Setting." *Journal of Environmental Psychology* 31 (1): 99–105. doi:10.1016/j.jenvp.2010.11.005.

R Core Team. 2017. "R: A Language and Environment for Statistical Computing." Vienna: R Foundation for Statistical Computing. https://www.r-project.org/.

Rashid, M., and C. Zimring. 2008. "A Review of the Empirical Literature on the Relationships Between Indoor Environment and Stress in Health Care and Office Settings: Problems and Prospects of Sharing Evidence." *Environment and Behavior* 40 (2): 151–90. doi:10.1177/0013916507311550.

Rice, Jennifer, Robert a Kozak, Michael J Meitner, and David H Cohen. 2006. "Appearance Wood Products and Psychological Well-Being." *Wood and Fiber Science* 38 (4): 644–59.

Ritz, Christian, Florent Baty, Jens C. Streibig, and Daniel Gerhard. 2015. "Dose-Response Analysis Using R." *PLoS ONE* 10 (12): 1–13. doi:10.1371/journal.pone.0146021.

Rovio, Suvi, Ingemar Kareholt, Eeva-Liisa Helkala, Matti Viitanen, Bengt Winblad, Jaakko Tuomilehto, Hilkka Soininen, Aulikki Nissinen, and Miia Kivipelto. 2005. "Leisure-Time Physical Activity at Midlife and the Risk of Dementia and Alzheimer's Disease." *The Lancet. Neurology* 4 (11). England: 705–11. doi:10.1016/S1474-4422(05)70198-8.

Rozin, Paul. 2005. "The Meaning Of 'natural' process More Important than Content." *Psychological Science* 16 (8): 652–58. doi:10.1111/j.1467-9280.2005.01589.x.

Rozin, Paul, Claude Fischler, and Christy Shields-Argelès. 2012. "European and American Perspectives on the Meaning of Natural." *Appetite* 59 (2). Elsevier Ltd: 448–55. doi:10.1016/j.appet.2012.06.001.

RStudio Inc. 2017. "RStudio." http://rstudio.com.

Sahlberg, Bo, Maria Gunnbjornsdottir, Argo Soon, Rain Jogi, Thorarinn Gislason, Gunilla Wieslander, Christer Janson, and Dan Norback. 2013. "Airborne Molds and Bacteria, Microbial Volatile Organic Compounds (MVOC), Plasticizers and Formaldehyde in Dwellings in Three North European Cities in Relation to Sick Building Syndrome (SBS)." *Science of the Total Environment* 444. Elsevier B.V.: 433–40. doi:10.1016/j.scitotenv.2012.10.114.

Sakuragawa, Satoshi, Yoshifumi Miyazaki, Tomoyuki Kaneko, and Teruo Makita. 2005. "Influence of Wood Wall Panels on Physiological and Psychological Responses." *Journal of Wood Science* 51 (2): 136–40. doi:10.1007/s10086-004-0643-1.

Salazar, James, and Jamie Meil. 2009. "Prospects for Carbon-Neutral Housing: The Influence of Greater Wood Use on the Carbon Footprint of a Single-Family Residence." *Journal of Cleaner Production* 17 (17). Elsevier Ltd: 1563–71. doi:10.1016/j.jclepro.2009.06.006.

Schwarzkopf, Matthew, Jian Huang, and Kaichang Li. 2010. "A Formaldehyde-Free Soy-Based Adhesive for Making Oriented Strandboard." *The Journal of Adhesion* 86 (3): 352–64. doi:10.1080/00218460903482549.

Sinha, Arijit, Rakesh Gupta, and Andreja Kutnar. 2013. "Sustainable Development and Green

Buildings.” *Drvna Industrija* 64 (1): 45–53. doi:10.5552/drind.2013.1205.

Soderbergh, Steven. 2012. *Haywire*. USA: Relativity Media.

Sztajzel, Juan. 2004. “Heart Rate Variability: A Noninvasive Electrocardiographic Method to Measure the Autonomic Nervous System.” *Swiss Medical Weekly* 134 (35–36): 514–22. doi:2004/35/smw-10321.

Terr, Abba I. 2009. “Sick Building Syndrome: Is Mould the Cause?” *Medical Mycology* 47 (Supplement 1): S217–22. doi:10.1080/13693780802510216.

Tonn, Bruce, and Gregg Marland. 2007. “Carbon Sequestration in Wood Products: A Method for Attribution to Multiple Parties.” *Environmental Science and Policy* 10 (2): 162–68. doi:10.1016/j.envsci.2006.10.010.

Topp, Christian Winther, Søren Dinesen Østergaard, Susan Søndergaard, and Per Bech. 2015. “The WHO-5 Well-Being Index: A Systematic Review of the Literature.” *Psychotherapy and Psychosomatics* 84 (3): 167–76. doi:10.1159/000376585.

Tsunetsugu, Yuko, Miyazaki, Yoshifumi, and Sato, Hiroshi. 2002. “The Visual Effects of Wooden Interiors in Actual-Size Living Rooms on the Autonomic Nervous Activities.” *Journal of Physiological Anthropology and Applied Human Science* 21 (6): 297–300. doi:10.2114/jpa.21.297.

Tsunetsugu, Yuko, Miyazaki, Yoshifumi, and Sato, Hiroshi. 2007. “Physiological Effects in Humans Induced by the Visual Stimulation of Room Interiors with Different Wood Quantities.” *Journal of Wood Science* 53 (1): 11–16. doi:10.1007/s10086-006-0812-5.

Tyrväinen, Liisa, Ann Ojala, Kalevi Korpela, Timo Lanki, Yuko Tsunetsugu, and Takahide Kagawa. 2014. “The Influence of Urban Green Environments on Stress Relief Measures: A Field Experiment.” *Journal of Environmental Psychology* 38. Elsevier Ltd: 1–9. doi:10.1016/j.jenvp.2013.12.005.

Ulrich, Roger S. 1984. “View through a Window May Influence Recovery from Surgery.” *Science* 224 (4647): 420–21. http://dx.doi.org/10.1016/S0272-4944(05)80184-7.

Ulrich, Roger S. 1991. “Effects of Interior Design on Wellness: Theory and Recent Scientific Research.” *Journal of Health Care Interior Design : Proceedings* 3 (11): 97–109.

Ulrich, Roger S., Robert F. Simons, Barbara D. Losito, Evelyn Fiorito, Mark A. Miles, and Michael Zelson. 1991. “Stress Recovery during Exposure to Natural and Urban Environments.” *Journal of Environmental Psychology* 11 (3): 201–30. doi:10.1016/S0272-4944(05)80184-7.

USGBC. 2011. “Green Building and LEED Core Concepts Guide.” United States Green Building Council.

Verma, Ira. 2016. “Use of Wood in Elderly Care.” In *Functional Wood*, edited by Yrsa Cronhjort, Mark Hughes, Mikko Paakkane, Karola Sahi, Pekka Tukiainen, Tomi Tulamo, and Katja Vahtikari, 70–73. Helsinki. http://www.ciriaf.it/ft/File/Pubblicazioni/pdf/1279.pdf.

White, Andrew, and Dieter Kleinböhl. 2013. "TCX Parser: An R Library for Parsing Garmin TCX Files." https://github.com/shiroandy/garmin-tcx-parser.

Whitmer, R William, Kenneth R Pelletier, David R Anderson, Catherine M Baase, and Gary J Frost. 2003. "A Wake-up Call for Corporate America." *Journal of Occupational and Environmental Medicine*. United States. doi:10.1097/01.jom.0000086280.38338.83.

Wickham, Hadley. 2009. *ggplot2: Elegant Graphics for Data Analysis*. New York: Springer Verlag. http://ggplot2.org.

Wilson, E. O. 1984. *Biophilia*. Harvard University Press. http://www.hup.harvard.edu/catalog.php?isbn=9780674074422&content=reviews.

World Health Organisation. 1998. "Wellbeing Measures in Primary Health Care/ The Depcare Project." *Report on a WHO Meeting*, 45. http://www.euro.who.int/__data/assets/pdf_file/0016/130750/E60246.pdf.

World Health Organization Europe. 2009. *Dampness and Mould. WHO Guidelines for Indoor Air Quality:dampness and Mould*. doi:10.1186/2041-1480-2-S2-I1.

Yu, C. W. F., and J. T. Kim. 2012. "Long-Term Impact of Formaldehyde and VOC Emissions from Wood-Based Products on Indoor Environments; and Issues with Recycled Products." *Indoor and Built Environment* 21 (1): 137–49. doi:10.1177/1420326X11424330.

Zimmerman, Greg. 2009. "Evidence-Based Design: From Health Care To Other Buildings?" *Building Operations Management*. http://www.facilitiesnet.com/green/article/Evidence-Based-Design-From-Health-Care-To-Other-Buildings-Facilities-Management-Green-Feature--11282.

ATTACHMENTS

Attachment 1	Burnard, Michael, and Andreja Kutnar. 2015. "Wood and Human Stress in the Built Indoor Environment: A Review." *Wood Science and Technology* 49 (5). Springer Berlin Heidelberg: 969–86. doi:10.1007/s00226-015-0747-3
Attachment 2	Burnard, Michael. 2017. "Bio-Based Materials and Human Well-Being in the Built Environment." In Performance of Bio-Based Materials, edited by Dennis Jones and Christian Brischke, 1st ed., 365–72. Duxford: Woodhead Publishing.
Attachment 3	Burnard, Michael, Anders Q. Nyrud, Kristian Bysheim, Andreja Kutnar, Katja Vahtikari, and Mark Hughes. 2017. "Building Material Naturalness: Perceptions from Finland, Norway and Slovenia." *Indoor and Built Environment* 26 (1): 92–107. doi:10.1177/1420326X15605162
Attachment 4	Naturalness Questionnaire in English, Finnish, and Slovene
Attachment 5	WHO-5 Well-being questionnaire in English
Attachment 6	Informed consent form in English
Attachment 7	KMERS application
Attachment 8	KMERS approval
Attachment 9	Stress Data processing and analysis in R.

Wood Sci Technol
DOI 10.1007/s00226-015-0747-3

Attachment 1

ORIGINAL

Wood and human stress in the built indoor environment: a review

Michael D. Burnard[1] **· Andreja Kutnar**[1,2]

Received: 28 August 2014

Abstract Individuals spend most of their time indoors, and therefore indoor environments are important aspects of one's life. Creating healthful indoor environments should be a priority for building designers, and evidence-based design decisions should be used to ensure the built environment provides healthful benefits to occupants. This review was conducted to examine the body of research studying wood use and human stress to determine the potential fit for wood in the restorative environmental design paradigm. Previous studies on psychophysiological responses to wood are reviewed, as are current methods for assessing stress in experimental settings. To date, studies examining the psychophysiological effects of wood use in interiors have revealed reduced autonomic stress responses when compared to rooms without and with less wood. Therefore, by increasing wood use in design paradigms seeking to bring the positive health benefits of nature into the built environment, like restorative environmental design, building designers may improve the well-being of building occupants. This review reveals further studies are needed to better understand the psychophysiological responses to wood, and suggests specific aspects of wood such as colour, quantity, and grain pattern should be examined and how stress and stress recovery should be analysed.

✉ Michael D. Burnard
michael.burnard@iam.upr.si

[1] Andrej Marušič Institute, University of Primorska, Muzejski trg 2, 6000 Koper, Slovenia

[2] Faculty of Mathematics, Natural Sciences and Information Technology, University of Primorska, Glagoljaška 8, 6000 Koper, Slovenia

Published online: 20 June 2015

Introduction

Today, people spend most of their time indoors and our physical surroundings are known to affect us (USGBC 2010; Kaplan 1995; Ulrich 1991). Therefore, creating healthy indoor environments such as offices, classrooms, living rooms, dining rooms, and bedrooms is an important aspect of creating healthy environments for building occupants. Natural environments have been shown to have positive effects on psychological well-being (Tyrväinen et al. 2014; Park et al. 2007; Hartig 2004; Hartig et al. 1997; Herzog et al. 1997; Kaplan 1995; Kaplan and Kaplan 1989). Therefore, bringing nature into the built environment may improve occupant well-being. Wood is a particularly interesting material for this purpose because it is already widely used and many products already exist on the market.

Though some design mechanisms are in place to bring nature into the built environment (Kellert 2005, 2008; Wilson 2008), people often remain segregated from nature and its restorative effects while indoors. Therefore, the impetus to bring nature indoors is to bring the restorative qualities of natural outdoor environments to people where they spend most of their time. One readily available means to address the issue is to use wood as functional or decorative indoor material. Indeed, using wood for interior treatments in indoor environments has been shown to have positive impacts on occupants, especially related to indicators of human stress (Fell 2010; Nyrud and Bringlimark 2010; Rice et al. 2006; Sakuragawa et al. 2005; Tsunetsugu et al. 2002, 2007). The application of natural materials and products to indoor environments is a major tenet of biophilic design and is part of an effort to bring the restorative elements of natural environments indoors (Derr and Kellert 2013; Kellert 2005, 2008). Furthermore, wood is a sustainable building material manufactured by nature with solar energy, which stores carbon (Sinha et al. 2013; Salazar and Meil 2009). After conversion to building products (e.g., lumber, wood-based panels), wood has only a minute amount of embodied energy compared to other building materials and increases the pool of stored carbon in the built environment creating a positive impact on climate change (Sinha et al. 2013).

As people become more aware of environmental concerns, they are slowly becoming interested in and willing to change or select aspects of their home related to sustainability (Park et al. 2013; Rice et al. 2006). Currently, these aspects of the home are often related to cost-savings through energy consumption reductions. However, studies examining home-like environments and stress indicate a preference for wooden elements and suggest restoration in home-like environments with interior wood may be enhanced (Tsunetsugu et al. 2007; Rice et al. 2006). Further findings and dissemination of the healthful impacts of indoor wood applications will educate homeowners and potential homeowners about choices for healthy interiors in their homes.

The objectives of this study were to review the methodologies, designs, and results of studies dealing with fundamental research assessing the psychophysiological indicators of occupant stress to interior wood treatments and provide a summary of how wood can be used in restorative environmental design by providing a connection to nature and positive health impacts for building occupants.

This review builds on the work of Nyrud and Bringlimark (2010), but focuses more narrowly on how wood may fit within the paradigm of restorative elemental design and explores underutilized methods for measuring human stress in this field. An overview of current methods for measuring stress levels and their potential use in studying restorative interior environments is also presented.

Methods

Critically evaluated articles examining human psychophysiological stress and wood in this review were sought in peer-reviewed English-language journals found in online databases. One PhD dissertation is included in the critical evaluation and three other studies are mentioned, which may demonstrate further interest in the field but are not published in peer-reviewed journals. The latter articles are mentioned for completeness, but do not offer qualified evidence for or against stress impacts in indoor environments with wood. Searches yielded four scholarly articles and the aforementioned PhD dissertation. The limited results of the search indicate that this field is in a nascent stage. It is therefore important to review the existing work and identify helpful results and troubling trends alike in order to improve future research in the field.

The scholarly articles and book (Kaplan and Kaplan 1989) related to restorative environments were gathered through searches of scholarly databases. In addition to these articles, this review has been supplemented with information from two books published on biophilic design that represent the most robust collection of information on that subject. The framework articles related to restoration and environments (e.g., Kaplan 1995; Ulrich et al. 1991) are included as a foundation, which has been built upon by many other researchers—including those who have worked with stress and wood in the built environment. Other articles (e.g., Hartig et al. 1997; Hartig 2004 etc.) provide a framework for understanding and assessing perceptions of restorative environments. Finally, articles and books providing context for functionalising restoration theories in the built environment, especially work by Kellert (2008) and Wilson (2008) amongst others, are discussed. These books present little scientific evidence, but identify current and potential applications of the restoration theories. In these cases, they also provide context in which studies examining restoration in the built environment can be conducted.

There are many more scholarly articles reviewing the use of biological indicators in psychophysiological stress experiments, and indeed robust review articles and meta-analyses of the research (cf. Dickerson and Kemeny 2004). Two articles are presented in more detail here to demonstrate useful methods to examine stress that are applicable to future studies examining human stress in the built indoor environment.

Restoration and human stress

In order to improve occupant well-being, important design decisions must be made which balance occupant needs and health with other goals such as environmental impacts and design aesthetics. To achieve these goals, designers must understand human stress, restoration and have building design paradigms that bring those issues to the forefront in their work. Many restoration theories stem from the field of environmental psychology and have helped to lay the foundation for new building design paradigms that emphasize occupant health, nature, and sustainability. Furthermore, these building design paradigms offer an opportunity for increased wood use.

Restoration theories

Hartig (2004) defines restoration as a process of renewal that replenishes a depleted social, psychological or physical resource. These resources have most often been depleted by an individual's effort to adapt to their environment (Hartig 2004). Early restoration theories focused on recovery from psychophysiological stress (Ulrich et al. 1991) and attention restoration (Kaplan and Kaplan 1989). Psychophysiological stress recovery theory posits that natural environments, and even views of these environments, will aid recovery from stressful events, including psychological stress and physical stress (e.g., recovery from surgery) (Ulrich 1984, 1991; Ulrich et al. 1991). Attention restoration theory (ART) focuses on understanding how individuals replenish their ability to exert attention on common tasks, such as those at the workplace that require directed attention (Hartig 2004; Hartig et al. 1997; Herzog et al. 1997; Kaplan 1995; Kaplan and Kaplan 1989). Though many experiments related to ART and psychophysiological stress recovery have focused on outdoor environments (or views of outdoor environments), some experiments have examined bringing nature into the built environment. For example, a recent study examined the effect the presence of plants in an office-like environment has on attention capacity and found participants performed better in the presence of plants after performing a task approximately 25 min in the test room, but not upon entering the test room (Raanaas et al. 2011). In an extensive review of the psychological benefits of indoor plants, Bringslimark et al. (2009) determined that although the evidence suggests indoor plants can provide psychological benefits, the heterogeneity amongst the methods and results may imply the benefits are contingent on the context of the encounter with indoor plants and the participants in the experiment. These concerns extend to experiments with wood or other natural materials indoors.

Many studies have found empirical evidence to support these theories, but the theories themselves remain open to elaboration as more evidence is collected regarding the restorative effects of nature (Hartig 2004). Studying the effects of wood on attention and psychophysiological stress restoration in the built environment may produce helpful and enlightening results.

Attachment 1

Experimental assessment of stress and psychophysiological responses to wood

Monitoring and measuring human stress

Monitoring recovery from stressful events is one way to explore and assess the restorative properties of indoor environments. However, stress is not a rigidly defined concept and there is disagreement regarding its precise definition (Cohen et al. 1995; Burchfield 1979). Despite these differences, Cohen et al. (1995) note how various definitions all refer to an interest in the process in which environmental demands exceed ones adaptive capabilities and lead to psychological and physiological changes in an individual. Excessive activations of these responses are worrisome because they may place individuals at risk for disease (Gaab et al. 2003; Lucini et al. 2002; Cohen et al. 1995).

Cohen et al. (1995) distinguish between three traditions in assessing the role of stress and note each makes different assumptions and therefore uses separate methodologies for measurements. These traditions are (Cohen et al. 1995):

- Environmental tradition—focuses on experiences triggered by one's social, natural, and cultural environment, which are objectively associated with substantial demands on the individual to adapt to the environment and uses environmental demands, stressors, or events as components of analysis.
- Psychological tradition—scrutinizes an individual's subjective assessment of their ability to cope with the adaptive demands of specific events using appraisals or perceptions of stressfulness in specific situations as metrics of stress level.
- Biological tradition—researchers determine stress levels by monitoring the activation of specific physiological systems established as responding to adaptive demands on the individual and use metrics of the activity for analysis of stress level.

Both the psychological and biological traditions have been employed to measure stress recovery in restorative environments. The methods associated with these traditions are more readily assessed in laboratory settings, and biological methods provide measures suitable for inferential comparisons. The environmental tradition is less useful in laboratory experiments because previous stress events are hard to place in relation to restorative environments and rely on self-reported assessments of the events, often at a much later date.

Psychological measures are subjective and rely on respondent assessment of their own situation. Subjective measures in this field are inherently challenging to make causal inferences from, but provide context and suggest direction for qualitative analysis (Cohen et al. 1995). On the other hand, biological methods for assessing stress often rely on monitoring the sympathetic and parasympathetic activity of the autonomic nervous system (ANS) and the output of the hypothalamic–pituitary–adrenocortical axis (HPA) of the endocrine system (Hellhammer et al. 2009;

Sztajzel 2004; Cohen et al. 1995; Kirschbaum and Hellhammer 1994). Though physiological responses to stress reveal themselves in a variety of measurable ways, these metrics are critical because they are the primary indicator of how stressed an individual becomes, and also how quickly and fully an individual recovers from stress.

Autonomic nervous system (ANS) responses to stressors include increased output of epinephrine, norepinephrine, increased blood pressure, heart rate, sweating, and constriction of peripheral blood vessels (Cohen et al. 1995). Methods for monitoring these responses have been employed in studies examining the effect wood has on occupant stress (Fell 2010; Tsunetsugu et al. 2002, 2007; Sakuragawa et al. 2005).

The HPA response is to release hormones, which help the body maintain homoeostasis when presented with a stress event (primarily cortisol, a corticosteroid, in humans) (Kirschbaum et al. 1993; Kirschbaum and Hellhammer 1994). Salivary free cortisol quantity is considered an effective, non-invasive measure of the HPA response to stress and therefore is useful to determine individual stress levels (Hellhammer et al. 2009; Gaab et al. 2003; Kirschbaum and Hellhammer 1994; Kirschbaum et al. 1993). Kirschbaum et al. (1992, 1993, 1999) and Kirschbaum and Hellhammer (1994) have extensively explored the HPA response to stress and have established cortisol levels as an effective measure of the response. Hellhammer et al. (2009) concluded salivary cortisol is useful as long as the researchers are aware of possible sources of variance in salivary cortisol and possible confounding variables are properly accounted for. These include sex, psychiatric health, and smoking (Hellhammer et al. 2009). Furthermore, cortisol levels naturally follow a circadian rythem throughout the day with peak release occurring soon after awakening and diminishing slowly throughout the day to their lowest levels in the evening (Dickerson and Kemeny 2004; Hellhammer et al. 2009). Dickerson and Kemeny (2004) note conducting experiments during the same time period for all participants and later in the day is one method to overcome this challenge. Furthermore, including a no-stressor control group or using within-subject experimental design is also suggested (Dickerson and Kemeny 2004). In addition to the circadian release cycle of cortisol, regular pulsatory cortisol releases do occur, but are quite stable within individual subjects suggesting a within-subject experimental design may compensate well for this attribute (Chrousos and Gold 1998).

Salivary free cortisol can be determined by assessing saliva samples gathered with a simple mouth swab, which can be stored and assessed at a later time (Gaab et al. 2003). Additionally, saliva samples are non-intrusive and practical for taking repeated measurements in a short period of time. Assessment of cortisol concentration in saliva can be determined by immunoassay methods described elsewhere (Dressendorfer et al. 1992).

While monitoring and assessing stress in any experiments, it is important to remember stress manifests itself in many ways, and the wide variety of autonomic and endocrine activity indicators used to monitor stress levels do not always correlate with each other. However, salivary free cortisol levels are an effective indicator of laboratory and real-world stress levels and have been found to correlate well with many other indicators of stress (Hellhammer et al. 2009; Dickerson and

Kemeny 2004; Lucini et al. 2002). Despite this, salivary free cortisol levels have not been used as an indicator of stress in experiments studying the psychophysiological responses to wood. This method has been used in monitoring restoration in outdoor environments (Tyrväinen et al. 2014; Park et al. 2007) and extensively in other stress-related experiments (Hellhammer et al. 2009; Gaab et al. 2003; Lucini et al. 2002; Kirschbaum and Hellhammer 1994; Kirschbaum et al. 1992, 1993).

Studies on psychophysiological responses to wood

Though there have been few studies directly examining the psychophysiological effects wood in the built environment has on people, they come to a similar conclusion: wood has a generally positive effect on occupants. The studies discussed here represent the extent of published scientific work on the topic. The studies all have examined biological indicators of psychophysiological stress or recovery from it and therefore provide insights into how wood use may provide benefits for stress reduction or improved recovery from stress. All but one of the following studies reported finding beneficial health impacts of wood in the built environment. In each case, the use of actual-size test environments allows easier application in practice. Many of the studies were done with limited sample sizes; however, they provide an impetus for further work in the field and a foundational framework for future studies.

Tsunetsugu et al. (2002) examined psychophysiological responses of subjects exposed to decorative wood applied to living room environments. The most basic room included white walls, with wood flooring, two covered (with drapes) windows, a coffee table, and one plant. The other room was identical to the basic room, but also included decorative wall and ceiling treatments made from wood. Ten subjects were preconditioned in a third room with a decorative wood treatment on the walls that was otherwise identical to the two test rooms. Baseline heart rate and blood pressure measurements were taken in this room. All subjects were exposed to two test environments: the basic room and the decorated test room. Subjects were randomly assigned to initial test rooms, but were exposed to both rooms consecutively. While heart rate and blood pressure decreased in the room with decorative wood application, the sample size was small and a potential serial effect could confound the findings. Furthermore, the objectives of the study were not clearly defined and therefore not clearly ascertainable in the study findings making interpretation of the findings and determining their applications challenging. Increasing sample size, clearly defined objectives and study outcomes that reflect them are critical in the early stage of defining a nascent research field.

Sakuragawa et al. (2005) assessed how material preference impacts blood pressure when viewing those materials. In this study, subjects were asked about their feelings for steel and wood and then exposed to a white steel wall and a wood wall in a random order. The study found subjects who reported liking steel maintained stable blood pressure readings during exposure to the steel wall. Those who reported disliking steel had increased blood pressure when exposed to the steel wall. Blood pressure decreased for subjects who reported liking wood when exposed to the wood wall. For those subjects who reported disliking wood, blood pressure neither increased nor decreased when exposed to the wood wall. The walls were presented in an otherwise empty room with no environmental context. The small sample size and the possibility of serial effects in this study limit inference of any findings. Additionally, the subjects were exposed to the experiment topic in the questionnaire before the test began. Avoiding the serial effect by using a within-subjects design on only two treatments for each subject could have improved the findings. Alternatively, using three subject groups (one control and one for each treatment) could have strengthened the findings as long as the sample sizes were increased. Notably, however, this study revealed how preference for materials might impact psychophysiological responses to different environments.

Tsunetsugu et al. (2007) assessed psychophysiological responses to different quantities of wood in a replicated living room environment. Four rooms were prepared for the experiment, a practice room to familiarize the subjects with the procedure of the experiment and three test rooms treated with different amounts of wood coverage. Each test room was designed to appear as a real, Japanese-style living room and was treated with 0, 45, and 90 % wood coverage. Heart rate and blood pressure were assessed as psychophysiological indicators of stress and health for 15 subjects during and after 90 s of exposure in each environment. Subjects were also asked to provide ratings of each of the three experimental environments. The 45 % covered room was the most favoured one and diastolic blood pressure was lower, but heart rate was higher in this room than the 0 % room. The 90 % room yielded the lowest blood pressure measurements, but subjects registered increased heart rates in the room. The short exposure time in each room provides only a small window into the immediate response of the subject to the environment. In this context, the results may not be indicative of the effect of spending significant time in indoor environments with wood. Though the sample size was small, the lack of correlation between preference and physiological response contradicts the preferential findings in Sakuragawa et al. (2005).

In the most robust study on the topic, Fell (2010) assessed sympathetic indicators of ANS stress responses for 119 subjects in four different office-like environments. In this factorial study, subjects were randomly assigned to only one room. The room treatments were: control (with non-wood furniture, and no plants), non-wood furniture with plants, wood furniture without plants, and wood furniture with plants. Subjects were monitored by an electrocardiogram and for electrodermal activity over three intervals: during a period of 10 min prior to the test to determine a baseline reading, throughout the test, and for a 10-min recovery period thereafter. To induce stress, subjects were given a Paced Auditory Serial Addition Test (PASAT, Gronwall 1977), which is considered a light stressor. Directly after the test period, subjects were asked to complete an environmental satisfaction questionnaire. The electrocardiogram provided analysis of cardiovascular responses to stress including inter-beat interval and heart rate variability. Electrodermal monitoring allowed for analysis of three stress responses: skin conductance levels, frequency of non-specific skin responses (F-NS-SCR), and amplitude of non-specific skin responses (A-NS-SCR). Measurements were compared between treatments during the baseline period (pre-test), testing period, and recovery period (post-test). Cardiovascular responses were not found to be significant in this study. However, there was strong evidence F-NS-SCR values were lower during the pre-test and recovery periods in the room with wood furniture and no plants, and some evidence of lower values during the test period in the same room. The study also examined the effects of indoor plants on stress responses, but neither a main effect nor interaction effect was discovered. This study provides the most robust examination of the psychophysiological effects of wood in the built environment. However, to better account for individual variations in stress responses a within-subjects design may have been useful. Similarly, profiling the individual's mood state and using a stronger stressor may have strengthened the findings.

Nyrud et al. (2010) examined restoration more directly in their study of interior wood treatments in hospital recovery rooms. This study compared recovery times, pain medication use, blood pressure, and self-reported measures of pain and stress of 197 orthopaedic patients in three different room types. Each room had either a view of nature, was treated with a piece of art, or was treated with a decorative wood element. No significant differences were found between rooms for any measure. Connecting these findings to Ulrich's (1984) prior study of hospital recovery where views of nature alone were found to have positive impacts on recovery raises questions about the amount of nature that must be visible to impact recovery times. That is, to what degree must nature be present to aid recovery times and reduce pain and are particular elements of nature more or less beneficial than others?

Additionally, studies carried out at the Human Research Institute in Austria have positively associated increased concentration, reduced strain, and reduced stress in schools with exposed wood in the built indoor environment (Grote et al. 2003, 2009; Kelz et al. 2007). These studies give further hints that humans experience positive health impacts when exposed to wooden elements indoors. However, the published scientific documentation for these studies lacks the detail necessary to fully accept the results.

Restorative environments and building design paradigms

In the case of both ART and psychophysiological stress recovery theory, the natural environment provides the individual with a means to restore themselves to a more complete state. These restorative environments exist in nature and provide a model for bringing the desired effects indoors. According to Kaplan (1995), the components of a restorative environment are:

1. Being away—the sense of being in a different environment (distance is not a necessary component of being away.)
2. Fascination—when ones attention is effortlessly focused on something.
3. Extent—feeling an area to be large. Well-designed paths can be used to make a small area seem larger.
4. Compatibility—the natural affinity humans seem to have for nature makes it a compatible environment.

While many of the elements of restorative environments may seem challenging to incorporate into building design, biophilic design provides guidance on how to bring nature indoors therefore a means to produce restorative indoor environments. Biophilic design is the incorporation of the principles of biophilia into building design (Kellert 2005, 2008). These principles are built around the concept of an innate human attraction to life and life-like processes (Kellert 2008). To create restorative indoor environments with biophilic principles, Wilson (2008) suggests being away can be addressed with indoor gardens, views of nature, and other features occupants can view or visit, which differ from a typical workstation. Similarly, design features may provide extent by varying ceiling height, including natural lighting, and other mechanisms (Wilson 2008). Natural patterns, shapes, and forms all provide targets of fascination, while compatibility is derived from evolved human relationships with nature (Kellert 2008; Wilson 2008).

There are six guiding principles of biophilic design. Briefly, they are (Kellert 2008):

1. Environmental features—making design choices, which reflect readily recognizable as aspects of nature. These features may range from views of nature, to water features within the building, to including a wide variety of indoor plants.
2. Natural shapes and forms—using elements of the built environment to replicate naturally occurring elements (such as trees).
3. Natural patterns and processes—using elements of design (such as materials, spaces, lighting, etc.), which through visual recognition, touch, scent, or sound remind occupants of growth, life, natural motion, and other elements of nature.
4. Light and space—diversity of colour, natural light, and variability in lighting levels are reminiscent of nature. Further, difference in size and shape of spaces in the built environment also remind us of nature.
5. Place-based relationships—connections to cultural and ecological elements linking geographically distinct locations with the built environment.
6. Evolved human relationships with nature—the connections humans have developed throughout the evolutionary history. For example, natural settings, such as forests, have provided shelter and safety, food and materials for survival.

One way to implement biophilic design in contemporary buildings is the restorative environmental design (RED) paradigm, which brings together the ideas of sustainable design and biophilic design (Derr and Kellert 2013; Kellert 2008). Additionally, RED attempts to promote a stronger connection between building occupants and nature, in order to inspire and motivate people to care for the environment. Derr and Kellert (2013) believe RED is the next evolution of “green” design. In principle, the goals of RED are to reduce environmental impacts of new buildings, to ensure buildings provide healthful benefits to the occupants, and to promote a stronger connection to nature.

Wood as an element of restorative environmental design

Wood is an ideal material for RED because it satisfies both general tenets of the design paradigm: sustainability and a connection to nature. Furthermore, research investigating psychophysiological responses to wood in the built environment supports the idea that indoor use of wood has positive health implications for occupants. Wood from healthy, well-managed forests is a renewable material and provides carbon storage (Hashimoto et al. 2002). It is unsurprising such a product, when used in appearance applications, also provides a connection to nature (Nyrud and Bringlimark 2010; Nyrud et al. 2010; Rice et al. 2006; Masuda 2004).

Wood is also an abundantly available material. The United Nations Food and Agriculture Organization (FAO) reports 30 % (~ 1.2 billion hectares) of the worlds forested area is used specifically for production purposes (FAO 2010). Another 949 billion hectares is designed as multifunction, which may include production purposes (FAO 2010). Usage from these forests includes industrial roundwood destined for wood products, fuelwood, and non-wood forest products. The majority of harvests from forests in Asia and Africa are used for fuelwood, while in Europe, North America and Oceania fuelwood harvests account for less than 20 % of the total (FAO 2010).

Furthermore, wood is known to sequester carbon throughout its lifetime when product lifetimes are sufficiently long (Salazar and Meil 2009; Tonn and Marland 2007; Hashimoto et al. 2002). In many industrialized countries, carbon storage in wood is greater than carbon released by activities inclusive of harvest and disposal and all steps in between (e.g., production, transportation) (Hashimoto et al. 2002). Therefore, effective use of wood products can reduce the amount of carbon released to the atmosphere. Correspondingly, well-managed forests provide a continuous supply of sustainable materials offering a variety of potential uses in the built environment.

Wood is an excellent building material because of its excellent strength-to-weight ratio and the variety of forms in which it can be used (e.g., in log form, lumber form, in fibre form, and in combination with other materials) (Kretschmann 2010; Stark et al. 2010). In the USA, more than 90 % of residential buildings are wood-framed and Japan is not far behind (Sinha et al. 2013). However, wood used in housing is often a concealed structural component, thereby limiting occupant interaction with it. Furthermore, wood use in non-residential construction is considerably less common than in residential construction (O'Connor et al. 2004). Beyond structural uses, wood is also an excellent architectural material for furniture and in decorative applications and is used in many forms such as solid wood, wood-based composites such as plywood, particleboard, and medium density fibreboard (Architectural Woodwork Institute 1994). Though exposed wood is present to some degree in many indoor environments, there are opportunities for greater utilization, which may contribute positively to occupant health (Fell 2010; Nyrud and Bringlimark 2010; Rice et al. 2006). Increasing wood use indoors by, for example, using exposed massive timber (cross laminated timber) may also offer improved indoor thermal comfort by buffering indoor temperature variations (Hameury and

Lundström 2004). Some common interior uses of wood are tables, chairs, cabinetry, desks, flooring, and moulding.

Furthermore, wood is generally viewed positively and evokes feelings of warmth, comfort, relaxation, and is reminiscent of nature (Fleming et al. 2013; Nyrud and Bringlimark 2010; Rice et al. 2006). Aspects of wood connecting humans to nature include recognition as a natural product, pattern, and colour (Fell 2010; Nyrud and Bringlimark 2010; Rice et al. 2006; Masuda 2004).

Though wood is often available in a variety of natural colours and patterns, the yellow-red hue with relatively low contrast is common and provides a positive, agreeable, and pleasant image (Masuda 2004). Colour contrast in wood is due to naturally occurring colour differences between earlywood and latewood, knots, and other natural wood features. In addition to the colour contrast provided by these features, they also construe pattern to the viewer (Fig. 1). This aspect of wood also contributes to the positive and agreeable image of wood and fits well with the fascination principle of restorative environments (Masuda 2004). The presence of knots in wood products, however, demonstrates cultural differences in our perception of it as a pleasing material. In Japan, the presence of knots are considered to diminish its purity, while in North America knots are considered natural and rustic (Rice et al. 2006).

Though not specifically mentioned as a biophilic material in *Biophilic Design* (Kellert et al. 2008), Fell (2010) notes that of the 30 images used as examples of biophilic indoor environments, 25 images feature wood. Furthermore, wood can address each of the six biophilic design tenets discussed in the previous section:

1. Environmental features—wood provides a direct link to nature, as it is a recognizable natural element.
2. Natural shapes and forms—patterns in wood grain are naturally developed and wood can be used in forms representative of the material as a living organism

Fig. 1 Douglas fir (*Pseudotsuga menziesii*) grain patterns reveal colour contrast and natural patterns

Fig. 2 Reception area of Sibelius Hall in Lahti, Finland, designed by architects Kimmo Lintula and Hannu Tikka

(such as the tree-like columns in Fig. 2, which serve both structural and aesthetic purposes).

3. Natural patterns and processes—grain patterns, colour spectrum, and the presence of knots evoke natural patterns and process (Fig. 1).
4. Light and space—wood naturally has colour diversity and can be stained in a variety of colours without losing its familiarity as a natural product, and it can easily be deployed in products of various sizes to address space concerns.
5. Place-based relationships—using locally sourced wood products can evoke a regional connection to nature, and historical and regional building methods, which utilized wood, may also be imitated.
6. Evolved human relationships with nature—trees and wood have long been used as source for shelter, tools, transportation, and art.

Environments that may benefit from restorative environmental design

There are many indoor environments in which occupants would benefit from RED. Recent research has focused on offices, hospital recovery rooms, schools, and homes (Derr and Kellert 2013; Fell 2010; Nyrud et al. 2010; Tsunetsugu et al. 2007; Ulrich 1984).

Office environments are considered to have an effect on occupational health (Danna and Griffin 1999). Emphasizing employee health is not only important to the individual, but also directly related to productivity and efficacy; Danna and Griffin (1999) cite work setting as an antecedent of well-being and health in the workplace.

Though they do not specifically suggest restorative environments as a solution, the connection between healthy employees and productivity is made clear. RED, therefore, is a potential solution to help ensuring healthy and productive workers.

Hospital stays after cholecystectomy surgeries were studied in a Pennsylvania hospital between 1972 and 1981 to examine whether the view from the recovery room might influence recovery times as well as analgesic and anxiety medication use (Ulrich 1984). Ulrich (1984) found patients with a view of nature recovered more quickly and used less analgesic medication. No significant results were found regarding anxiety medication, except that analgesic dosages may have impacted the amount of anxiety medication taken.

A case study of four children's environments (three schools and one "learning environment") revealed the variety of ways RED was implemented in schools and school-like settings (Derr and Kellert 2013). In these environments, Derr and Kellert (2013) report finding many aspects of sustainable building such as energy reduction through passive and active solar systems, rooftop gardens, sustainable and local material use, use of recycled material, rainwater harvesting, and even composting toilets. Similarly, the authors identified many biophilic features including, natural materials in the building construction and curriculum, direct exposure to plants, animals and water, connections to ecological place, exhibits including natural materials, natural forms and motifs, nature-based colour palettes, and the transformability of indoor and outdoor spaces—meaning spaces where children can interact with, affect, and manipulate their environments (Derr and Kellert 2013). Children generally reported positive feelings about their schools. Furthermore, the restorative elements of the environments served as potential learning opportunities. That is, the natural elements in the schools were directly used to teach lessons, but also as part of the environmental construct connecting the children to nature. By connecting children to nature at an early age and reinforcing the human–nature connection sustainability principles may also be more readily embraced (Derr and Kellert 2013). The authors identified the need for more research to examine the impact restorative environmental design has on fostering enhanced understanding of the natural world and its processes. Identifying these benefits may provide children and students with increased learning capacity, reduced stress, and improved overall well-being. Additionally, promoting a stronger connection to nature may inspire and motivate individuals to care for their environment.

Discussion and conclusion

Whether at home, at work, or at school indoor environments affect buildings occupants. In workplaces healthier environments can reduce sick leave and increase productivity, which directly impacts profitability (Danna and Griffin 1999). Similarly, in addition to enhancing relationships with nature healthy school environments could reduce illness and improve student performance and learning.

Wood is a well-suited building material for sustainable design because it sequesters carbon throughout its life cycle and is derived from a renewable resource. Furthermore, because wood is a material that is well recognized as being natural, it is an excellent material for biophilic design and, consequently, RED. However, a more robust body of research must be developed in order to more tightly integrate wood use with RED. Although few studies directly examined the restorative properties of wood as a material for the built indoor environment, those that have suggest interior wood use provides restorative benefits and positive health impacts to occupants. Questions remain about the types of wood and the attributes (e.g., colour, pattern, solid, composite) expected to provide restorative benefits, and about the quantity of wood required to induce a benefit. While these questions remain specific, guidance on interior wood use in RED is premature. More studies with stronger designs are necessary to close this knowledge gap.

Recommendations for future experiments

To investigate wood use for RED future studies should emphasize studying different attributes of wood including colour, pattern, and type (e.g., solid wood, wood-based composites such as plywood, particleboard, medium density fibreboard). To gain a more complete understanding of the stress responses to wood, these studies should examine HPA axis responses to stress in indoor environments using salivary cortisol as an indicator of the response along with other indicators, when feasible. In future experiments, recovery from the stress events should be specifically examined by extending the period during which participants are monitored for stress responses to more fully understand how aspects of the interior environment affect recovery and restoration. Previous research from other fields examining stress can serve as a guide for studies examining wood and human stress in the built environment. For example, the work of Lucini et al. (2002) and Gaab et al. (2003) provides helpful frameworks for studying real-world stress and monitoring recovery from stress while using salivary free cortisol as an indicator of stress. Thoughtful experimental design can address concerns about both the circadian nature of cortisol levels and its pulsatory releases. For example, using within-subjects design can be effective in overcoming individual differences in pulsatory cortisol release, while simply testing subjects at similar times of day (for example, during the afternoon) is useful to address circadian cortisol levels. Finally, studying the relationship between interior wood use and human stress in diverse contexts will provide more robust results that are more readily applicable in real-world situations.

If future studies exploring the restorative effects of wood in the built indoor environment provide evidence of positive health impacts, more wood should be used as a material in restorative environmental design.

Acknowledgments The authors would like to acknowledge the Slovenian Research Agency for financial support within the frame of the project Z4-5520 and the Italy-Slovenia Cross-border Cooperation Programme 2007–2013 for financial support within the project EnergyViLLab.

References

Architectural Woodwork Institute (1994) Architectural woodwork quality standards, 6th edn. Architectural Woodwork Institute, Centerville

Bringslimark T, Hartig T, Patil GG (2009) The psychological benefits of indoor plants: a critical review of the experimental literature. J Environ Psychol 29(4):422–433

Burchfield SR (1979) The stress response: a new perspective. Psychosom Med 41(8):661–672

Chrousos GP, Gold PW (1998) A healthy body in a healthy mind—and vice versa—the damaging power of "uncontrollable" stress. J Clin Endocrinol Metab 83(6):1842–1845

Cohen S, Kessler RC, Gordon LU (1995) Measuring stress: A guide for health and social scientists. In: Cohen S, Kessler RC, Gordon LU (eds) Measuring stress: a guide for health and social scientests. Oxford University Press, New York

Danna K, Griffin RW (1999) Health and well-being in the workplace: a review and synthesis of the literature. J Manag 25(3):357–384

Derr V, Kellert SR (2013) Making children's environments "R.E.D.": restorative environmental design and its relationship to sustainable design. In: Pavlides E, Wells J (eds) Proceedings of the 44th annual conference of the environmental design research association. Providence, Rhode Island, 29 May–1 June 2013

Dickerson SS, Kemeny ME (2004) Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. Psychol Bull 130(3):355–391

Dressendorfer RA, Kirschbaum C, Rohde W, Stahl F, Strasburger CJ (1992) Synthesis of a cortisol-biotin conjugate and evaluation as a tracer in an immunoassay for salivary cortisol measurement. J Steroid Biochem 43(7):683–692

FAO (2010) Global forest resource assessment 2010 main report. United Nations Food and Agriculture Organization United Nations Food and Agriculture Organization, Rome

Fell D (2010) Wood in the human environment: restorative properties of wood in the built indoor environment. PhD Dissertation, University of British Columbia, Vancouver, BC, Canada

Fleming R, Wiebel C, Gegenfurtner K (2013) Perceptial qualities and material classes. J Vis 13(8):1–20

Gaab J, Blättler N, Menzi T, Pabst B, Stoyer S, Ehlert U (2003) Randomized controlled evaluation of the effects of cognitive-behaviour stress management on cortisol responses to acute stress in healthy subjects. Psychoneuroendocrinology 28(6):767–779

Gronwall DMA (1977) Paced auditory serial-addition task: a measure of recovery from concussion. Percept Mot Skills 44(2):367–373

Grote V, Lackner H, Muhry F, Trapp M, Moser M (2003) Evaluation of the effects of a Pine wood environment on circulation, sleep, condition and vegetative regulation. Research report, Joanneum Research mbH, Institute for Non-Invasive Diagnosis

Grote V, Avian A, Frühwirth M, Hillebrand C, Köhldorfer P, Messerschmidt D, Resch V, Schaumberger K, Zieringer C, Mayrhoffer M, Moser M (2009) Health effects of solid wood trim in the main school building in the Enns Valley. Research report, Human Research Institute, Joanneum Research mbH

Hameury S, Lundström T (2004) Contribution of indoor exposed massive wood to a good indoor climate: in situ measurement campaign. Energy Build 36(3):281–292

Hartig T (2004) Toward understanding the restorative environment as a health resource. In: Open space: people space. Engaging with the environment. Edinburgh, 2004. OPENspace Research Centre. http://www.openspace.eca.ac.uk/conference/proceedings/PDF/Hartig.pdf. Accessed 24 Nov 2013

Hartig T, Korpela K, Evans GW, Gärling T (1997) A measure of restorative quality in environments. Scand Hous Plan Res 14(4):175–194

Hashimoto S, Nose M, Obara T, Moriguchi Y (2002) Wood products: potential carbon sequestration impact on net carbon emissions in industrialized countries. Environ Sci Policy 5(2):183–193

Hellhammer DH, Wüst S, Kudielka BM (2009) Salivary cortisol as a biomarker in stress research. Psychoneuroendocrinology 34(2):163–171

Herzog TR, Black AM, Fountaine KA, Knotts JD (1997) Reflection and attentional recovery as distinctive benefits of restorative environments. J Environ Psychol 17(2):165–170

Kaplan S (1995) The restorative benefits of nature: toward an integrative framework. J Environ Psychol 15(3):169–182

Kaplan R, Kaplan S (1989) The experience of nature: a psychological perspective. Cambridge University Press, Cambridge

Kellert SR (2005) Building for life: designing and understanding the human-nature connection, 1st edn. Island Press, Washington

Kellert SR (2008) Dimensions, elements and attributes of biophilic design. In: Kellert RS, Heerwagen JH, Mador ML (eds) Biophilic design: the theory, science and practice of bringing buildings to life, 1st edn. Wiley, Hoboken, pp 3–19

Kellert SR, Heerwagen JH, Mador ML (2008) Biophilic design: the theory, science and practice of bringing buildings to life, 1st edn. Wiley, Hoboken
Kelz C, Lackne, H, Avian A, Moser M (2007) Solid Fir furniture Reduces strain falling on and after concentration periods. In: 7th biennial conference on environmental psychology, Sept 9th–12th 2007, Bayreuth
Kirschbaum C, Hellhammer DH (1994) Salivary cortisol in psychoneuroendocrine research: recent development and applications. Psychoneuroendocrinology 19(4):313–333
Kirschbaum C, Wust S, Strasburger CJ (1992) 'Normal' cigarette smoking increases free cortisol in habitual smokers. J Life Sci 50(6):435–442
Kirschbaum C, Pierke K-M, Hellhammer DH (1993) The 'trier social stress test'—a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology 28(1–2):76–81
Kirschbaum C, Kudielka B, Gaab J, Schommer N, Hellhammer D (1999) Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamus–pituitary–adrenal axis. Psychosom Med 61(2):154–162
Kretschmann DE (2010) Commercial lumber, round timbers, and ties. General report, United States Forest Service, Madison
Lucini D, Norbiato G, Clerici M, Pagani M (2002) Hemodynamic and autonomic adjustments to real life stress conditions in humans. Hypertens 39(1):184–188
Masuda M (2004) Why wood is excellent for interior design? From vision physical point of view. In: EWPA (ed) Proceedings 8th world conference on timber engineering. Lahti, Finland, June 2004. Engineered Wood Products Association, Paper 186
Nyrud A, Bringlimark T (2010) Is interior wood use psychologically beneficial? A review of psychological responses toward wood. Wood Fiber Sci 42(2):202–218
Nyrud A, Bysheim K, Bringslimark T (2010) Health benefits from wood interior in a hospital room. In: SWST (ed) Proceedings of the international convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe—Timber committee. Geneva, Switzerland, 11–14 October 2010. Society of Wood Science and Technology and United Nations Economic Commission for Europe, Paper WS-56
O'Connor J, Kozak R, Gaston C, Fell D (2004) Wood in nonresidential buildings: opportunities and barriers. Forest Prod J 54(3):19–28
Park B, Tsunetsugu Y, Kasetani T, Hirano H, Kagawa T, Sato M, Miyazaki Y (2007) Physiological effects of Shinrin-yoku (taking in the atmosphere of the forest)—using salivary cortisol and cerebral activity indicators. J Physiol Anthropol 26(2):123–128
Park M, Hagishima A, Tanimoto J, Chun C (2013) Willingness to pay for improvements in environmental performance of residential buildings. Build Environ 60:225–233
Raanaas RK, Evensen KH, Rich D, Sjøstrøm G, Patil G (2011) Benefits of indoor plants on attention capacity in an office setting. J Environ Psychol 31(1):99–105
Rice J, Kozak RA, Meitner MJ, Cohen DH (2006) Appearance wood products and psychological well-being. Wood Fiber Sci 38(4):644–659
Sakuragawa S, Miyazaki Y, Kaneko T, Makita T (2005) Influence of wood wall panels on physiological and psychological responses. J Wood Sci 51(2):136–140
Salazar J, Meil J (2009) Prospects for carbon-neutral housing: the influence of greater wood use on the carbon footprint of a single-family residence. J Clean Prod 17(17):1563–1571
Sinha A, Gupta RK, Kutnar A (2013) Sustainable development and green buildings (Održivi razvoj i zelena gradnja). Drvna Industrija 64(1):45–53
Stark NM, Cai Z, Carll C (2010) Wood-based composite materials: panel products, glued-laminated timbers, structural composite lumber, and wood-nonwood composite materials. General report, United States Forest Service United States Forest Service, Madison
Sztajzel J (2004) Heart rate variability: a noninvasive electrocardiographic method to measure the autonomic nervous system. Swiss Med Wkly 134:514–522
Tonn B, Marland G (2007) Carbon sequestration in wood products: a method for attribution to multiple parties. Environ Sci Policy 10(2):162–168
Tsunetsugu Y, Miyazaki Y, Sato H (2002) The visual effects of wooden interiors in actual-size living rooms on the autonomic nervous activities. J Physiol Anthropol 21(6):297–300
Tsunetsugu Y, Miyazaki Y, Sato H (2007) Physiological effects in humans induced by the visual stimulation of room interios with different wood quantities. J Wood Sci 53(1):11–16
Tyrväinen L, Ojala A, Korpela K, Lanki T, Tsunetsugu Y, Kagawa T (2014) The influence of urban green environments on stress relief measures: a field experiment. J Environ Psychol 38:1–9

Ulrich R (1984) View through a window may influence recovery from surgery. Science 224(4647):420–421

Ulrich R (1991) Effects of interior design on wellness: theory and recent scientific research. J Health Care Inter Des 3(1):97–109

Ulrich R, Simons R, Losito B, Fiorito E, Miles M, Zelson M (1991) Stress recovery during exposure to natural and urban environments. J Environ Psychol 11(3):201–230

USGBC (2010) Green building and LEED core concepts. USGBC United States Green Building Council (USGBC), Washington, DC

Wilson A (2008) Biophilia in practice: Buildings that connect people with nature. In: Kellert SR, Heerwagen JH, Mador ML (eds) Biophilic design: the theory, science and practice of bringing buildings to life, 1st edn. Wiley, Hoboken, pp 325–333

CHAPTER 6.7

Bio-based materials and human well-being in the built environment

Michael D Burnard[1,2]

[1]University of Primorska, Andrej Marušič Institute, Muzejski trg 2, 6000-Koper, Slovenia, michael.burnard@iam.upr.si

[2] Abelium R&D, Kajuhova 90, SI-1000 Ljubljana

1 Introduction

The built environment has a strong impact on both human and environmental health. Buildings and the infrastructure surrounding them consume great quantities of materials and energy during construction, operations, and eventual deconstruction at the end of the buildings life (Sinha et al., 2013). There are accepted measures for analysing the environmental impacts of buildings and the materials and activities surrounding them such as life cycle costing and assessment (ISO/IEC, 2006). As with environmental impacts, the built environment affects the people who use it in a variety of ways including, psychologically, socially, and physiologically. However, unlike the environmental impacts of the built environment, the methods for understanding how buildings impact their users are not currently as well established.

Human health impacts in buildings stem from different elements and aspects of the building itself. These include the environment and location of the building, its design, materials, maintenance, accessibility, safety, and the management of the building (in terms of thermal comfort, lighting, etc.). Certain health impacts are easier to understand, and control, than others. For example, emissions from materials (such as formaldehyde) in buildings are readily assessable and limits are placed on these emissions by legislation in many places [EPA, 2016; EC, 1992]. Emissions measurements, though, are an indirect measure of the impact buildings have on human health impact, and are focused on preventing harm.

Harm prevention is an incredibly important aspect of building design, maintenance, and management, but modern building design paradigms are pushing beyond preventative measures and are beginning to incorporate both environmental and human health interventions that are intended to create positive effects (Derr and Kellert, 2013; Dolan et al., 2016; Mang and Reed, 2012). For building users, these positive effects include health and behaviour impacts, which can translate to reduced pressures on health care systems, better job performance, and more time at work (Danna and Griffin, 1999). This chapter will examine some of the primary concerns related to human health in the built environment, the interventions that can be used to create positive health impacts, as well as the design paradigms and research examining positive health interventions in the built environment. In each case, emphasis will be placed on the role of bio-based materials.

2 Primary concerns with human well-being in the built environment

There are a variety of suggested frameworks for understanding and mitigating the negative effects buildings can have on occupants. For example, Kellert (2008) identifies six key principles for implementing biophilic design, which imparts improved human well-being in the built environment by supporting the innate connection between humans and life or life-like processes in nature. These principles are: including environmental features in the building, using natural shapes and forms, including natural patterns and processes, varying light and space, supporting place-base relationships, and supporting the evolved human relationship with nature. Another recent framework is the SALIENT checklist to understand how buildings affect what we do and how we feel (Dolan et al., 2016). This list itemises seven factors that affect human well-being in the built environment: sound, air, lighting, image, ergonomics, nature, and tint (colour) (Dolan et al., 2016).

When negative human health and well-being effects associated with spending time in built environments manifest, they do so in several ways ranging from increased time away from work, greater stress, reduced work performance, and direct health impacts. Briefly, these effects may be:

- Symptoms of illnesses: frequently observed as a variety of potentially connected symptoms often referred to as sick building syndrome (SBS) (Finnegan et al., 1984).
- Psychophysiological stress: increased physical or social stress and a reduced ability to recover from stress (Fell, 2010).
- Directed attention deficits: reduced ability to recover from focusing one's attention (Hartig et al., 1997),
- Ergonomic problems: musculoskeletal issues related to a lack of ergonomic interventions (Attaianese and Duca, 2012).

The links between elements of buildings and the effect imparted on building users isn't always clear, and in many cases a combination of elements are likely to jointly contribute. Furthermore, because place and local traditions play a role in how users perceive their environment, the effect of different design decisions may vary between places. While culture may impact how users perceive their built environment, perceptions of building material naturalness are unlikely to vary significantly (Burnard et al., 2015). The combination of material use and design choices that reflect natural environments are important aspects of imparting positive health impacts for building users.

Beyond perceptions, material selection also has direct effects on health impacts in the built environment, especially related to indoor air quality. Bio-based materials, and the adhesives, coatings, other treatments used on them, release volatile organic compounds (VOCs) into the environment (Gallego et al., 2009; Jensen et al., 2001; Manninen et al., 2002). The amount and type of VOCs vary based on species, treatment, and product (cf. Bulian and Fragassa, 2016). Regulations limiting the type or amount present in products used in buildings exist in many places, and are often further limited when green building systems are followed (Bulian and Fragassa, 2016).

Understanding the performance of bio-based materials in terms of fitness for use (e.g., structural suitability), their environmental impact, and their potential for contributing to positive health impacts in the built environment is critical for developing building paradigms that focus on positive impacts, instead of minimising negative impacts.

2.1 Psychophysiological well-being

Psychophysiological well-being can be considered as a state of a network of interdependent mental, emotional, and physiological systems (McCraty et al., 2009). Within this framework, the places people spend their time can affect their well-being by interacting with each system in the psychophysiological network. VOCs and other contaminants in the air directly impact physiological systems, which, in turn, affect mental and emotional state. Similarly, perceptions of the environment impact emotional and mental states and cause direct physiological impacts. Physical aspects of the built environment such as ergonomic function, safety, and accessibility also affect an individual in this framework.

The benefits that may be imparted by ones built environment include:

- reduced psychophysiological stress, the ability to cope better with stressful events and situations, and increased recovery from stress
- reduced time away from work due to illness
- increased connection with and care for the natural environment
- support for increased social cohesion
- support for more activity in typically sedentary lifestyles

These benefits and others can be imparted by user perceptions of materials, building design and ergonomic interventions, views and inclusion of nature in the built environment, and material properties affecting indoor air quality, thermal comfort, etc.

Monitoring human well-being in the built environment requires understanding how humans interact with their surroundings, how perceived and physical stress are affected by buildings, how materials and building systems management impact indoor air quality, and many other aspects of the complex relationship between humans and the built environment. In many cases, common monitoring systems are indicative or indirect measurements of impacts on occupants and therefore difficult to directly relate to health impacts.

For example, measurements such as temperature, relative humidity, lighting, and air flow are straightforward to collect and interpret, but determining their impact on human health is more challenging. Upper and lower limits are generally suggested for thermal comfort indicators (e.g., temperature, relative humidity) in standards such as ISO 7730:2005 (ISO, 2005). These limits are expected to provide an acceptable level of comfort, but the specific contribution of materials to these values is not well known. Properties of bio-based materials such as thermal capacity or latent heat impact indoor environments, and if better understood may be able to be used to reduce mechanical interventions in the built environment (Kraniotis et al., 2016).

Direct measurements of human well-being are more difficult to collect. Subjective measures of well-being may be derived by collecting user mood and comfort status, reports of illness, sick days taken, etc. but require human input and may vary greatly between users. Biological indicators of health and well-being (particularly stress and activity) are useful indicators of the actual state of building users, but are more difficult and occasionally intrusive to collect. This difficulty, and the nascent state of the field, have led to relatively few studies into human health and well-being impacts of materials or buildings (for a review of human stress studies related to wood, see Burnard and Kutnar, 2015). Despite this shortcoming, many aspects that are considered to be strongly related to occupant well-being are studied for different building materials, often in an effort to explore the properties new processes and products or to prove they meet defined standards for use.

2.2 Factors impacting well-being in buildings

The primary factors that impact human well-being in the built environment are related to materials, building and product performance, ergonomics, user perceptions of their environment, and the activities users perform in buildings.

Many aspects of each factor contribute to the impact felt by building users. For example, the material (e.g., an exposed wood beam) can be perceived by the user to impart safety (as a structural element), warmth (in colour and thermal comfort), restoration (associated with nature); will have specific properties related to acoustics, thermal comfort, lighting, VOC emissions, etc.; and may be functionalised beyond its basic intent (e.g., supporting other elements of the building). These factors can be influenced by processing, maintenance, natural processes (such as decay, changes in colour), etc.

Material and product related

Here, material and product related factors that impact occupant health are considered to be those that are directly related to the material, product components, and processes. Wood and other bio-based materials are known to contain and emit VOCs and other contaminants as they go through drying processes (natural or otherwise). In recent years, formaldehyde has been a primary concern and has been limited by statue in many areas (e.g., by the Environmental Protection Agency (EPA) in the US (EPA, 2016), by the European Commission in EN 120 (EC, 1992), and other agencies worldwide).

VOC emissions from wood and other bio-based materials are biogenic, and are part of natural processes. The amount and type of emissions are dependent on species and affected by processes such as drying or thermal treatment. For example, differences in the types and quantities of emissions varied between air dried and heat-treated Scots pine, as reported by (Manninen et al., 2002). It is possible for reactions to occur as wood dries causing emissions of compounds not originally present in the material as well (Milota, 2000). Subjecting wood to thermal processes (e.g., drying, heat-treating, thermal-mechanical treatments) before use can limit the amount of emissions after installation (Milota et al., 2007).

Emissions released by composite products, especially those of glued composites using adhesives with formaldehyde are also a major concern as they are present to a great degree in the furniture used in buildings, and other building components (Huang and Li, 2007; Jang et al., 2011). While alternatives (e.g., soy-based adhesives) are under development, their performance often suffers in terms of strength or susceptibility to water (Huang and Li, 2007; Schwarzkopf et al., 2010).

Other processes impose similar concerns: wood preservatives, fire retardants, and coatings often contain contaminants, which may be emitted into buildings or outdoor spaces (Yu and Kim, 2012). The inclusion of these contaminants in building products impedes their use in recycling schemes, as well (Yu and Kim, 2012).

Processes that affect appearance (such as some coatings or mechanical processing that can obscure recognisability as a natural product) are likely to reduce the ability of occupants to gain restorative effects from the materials (Burnard et al., 2015). Similarly, these processes are likely to impact user preference for materials as well, which can have similar psychological effects on building occupants. Coatings and other treatments also impact the degree of perceived warmth (a haptic response felt by users when touching a material) (Bhatta and Kyttä, 2016). In principle, when a material feels warmer at a lower temperature than another, energy used to heat the material (e.g., flooring) can be saved while maintaining acceptable levels of thermal comfort (Bhatta and Kyttä, 2016).

Performance

The performance of materials in buildings relies on a complex system that includes building systems management that control electronic and mechanical components, materials, use patterns, outdoor weather, building design, and more. Bio-based materials can play many roles in building performance. Some recent research trends have been to functionalise wood and wood products, along with other bio-based materials, to provide improved material properties such as fire retardancy, hydrophobicity, and resistance to weathering (Petrič, 2013).

In the presence of moisture, bio-based materials can be a nutrient source for fungi in build environment (WHO-E, 2009). Fungi can have a variety of negative effects ranging from damage to the buildings structure (in the case of wood-rotting fungi) and can become airborne potentially harming building users (WHO-E, 2009). Fungi, moulds, and associated bacteria are known to emit VOCs (often termed microbial volatile organic compounds – MVOCs), allergens, and a variety of toxins (WHO-E, 2009; Sahlberg et al., 2013). However, evidence that inhalation of these substances cause human health problems remains unconvincing (as opposed to evidence that ingestion of fungi causes health problems) according to Terr (2009). While studies continue to examine airborne toxins related to moisture and fungi in the built environment, experimentally controlled studies are impossible due to health concerns (Terr, 2009). Nonetheless, limiting the fungal growth (and other phenomena related to moisture and dampness) in buildings should be a key aspect of material selection, building design, and construction methods.

The varying colour, treatments, and use of bio-based products indoors impacts lighting needs and the visual comfort of spaces in buildings (Jafarian et al., 2016). There is an opportunity to optimise artificial and day lighting, as well as occupant visual comfort by using wood indoors of various colours, patterns (imparted by grain or designed), and amounts to alter brightness, colour temperature, perceived glare, and other attributes through intelligent use bio-based products (Jafarian, et al., 2016).

Acoustics in buildings are also affected by material selection for structural and decorative materials. Bio-based materials, including flax, cellulose, wood wool, and cork have been shown to be effective in providing good acoustic performance (Asdrubali, 2006).

Human Factors/Ergonomics

Human Factors/Ergonomics (HFE) is a scientific discipline that is itself primarily concerned with human well-being and performance; it seeks to optimise systems to maximise its concerns (Dul et al., 2012). HFE enhances well-being by implementing design changes and interventions in buildings, products, and systems to reduce negative impacts on users. The types of interventions may relate to:

- safety (e.g., railings in bathrooms, along walkways, etc.),
- accessibility (e.g., ramps, room size, optimising worker movement in an office or factory), or,
- activity (e.g., reducing time in sedentary positions while at work, providing activities to mitigate the effect).

There are many opportunities for bio-based materials to play a role in these interventions, and the overall well-being goals are well aligned with optimised wood use in buildings.

Using wood as a safety intervention for the elderly can help users navigate and safely use bathrooms (Verma, 2016). The colour contrast of wood and typically white porcelain components of bathroom environments helps users (especially those with diseases like Alzheimer's) to more easily recognise and use components of bathrooms (Verma, 2016). Similarly, bio-based may be used for a variety of interventions including ergonomically designed furniture, built-up handles on utensils, railings, ramps, etc.

Design related

The variety of HFE, material and product, and performance factors discussed above require an overarching framework to produce positive human health impacts. Several design paradigms exist for including elements of nature in the built environment, including biophilic design (Kellert, 2008), restorative environmental design (RED) (Derr and Kellert, 2013), regenerative design (Mang and Reed, 2012), restorative environmental and ergonomic design (REED) (Burnard et al., 2016). These design paradigms each place emphasis on including nature in the built environment, however except for REED, the focus is less on material choices and more on access to nature through views of windows, water features, plants, etc. The specifics of material selection are often overlooked and relegated to concerns of cost and environmental impact. While these concerns are valid, creating positive impacts requires making evidence based decisions for a variety of design choices.

These design paradigms show continual growth in the treatment of nature and naturalness in building design. However, in all cases, access to more evidence of the various effects is needed to inform design decision. Furthermore, documentation on how to properly use materials in to achieve positive effects is needed. In addition to conducting and reporting research, scientists, designers, material and product manufacturers, users, and other stakeholders must come together and develop design strategies and documentation that create positive human health impacts.

2.3 Measuring impact

Measuring the impact of design decisions, material selection, and building use on human health is often a considerable challenge. In cases where standards exist to determine indirect health indicators (e.g., to determine VOC emissions, thermal properties, acoustic properties, etc.) these can be used as an initial step in determining the impact products or materials will have on users in the built environment. However, these indicators do not directly reveal the health impacts of materials and their use, they reveal an aspect to be considered in design and material selection.

The effects building material selection has on human health can be determined in a variety of ways, including monitoring human stress and stress recovery. Stress can be monitored unobtrusively in experimental and real-life settings using indicators such as heart rate, heart rate variability, galvanic skin response, and salivary free cortisol levels – ideally using multiple indicators (Burnard and Kutnar, 2015). These methods have been used to determine the stress recovery effects of outdoor natural environments (e.g., Tyrväinen et al., 2014). Stress is a direct indicator of an important health impact that designers can readily consider once more evidence is gathered and reported.

Self-reported psychological assessment can also be a useful method for understanding occupant health in the built environment. Many scales and methods exist for determining user perceptions, mood, and well-being. For example, the Perceived Restorativeness Scale (PRS) was originally developed by Hartig et al. (1996) and further developed by many other researchers including Pasini et al. (2014) who developed a shortened version (11 item vs. 26 item). This scale has been used in many studies to describe how users perceive various indoor and outdoor environments (e.g., Hug et al., 2009; Hippo and Ogunseitan, 2011). Another common scale developed by Engvall et al. (2004) can be used to identify the degree to which a building may contribute to sick building syndrome.

Ideally, studies should be conducted in real use situations (i.e., either in mock environments or actual environments that are experimentally controlled) that allow control for the many factors that may affect health outcomes. While these studies can be expensive and lengthy, a body of evidence must be developed to appropriately determine the potential health impacts bio-based materials may have in the built environment.

3 Future prospects for bio-based materials and human health

Bio-based materials have the potential to contribute to positive human health impacts in the built environment. Bio-based materials can be functionalised in specific ways to improve indoor environmental quality by a variety of processes. They can provide a strong connection to nature which is associated with restorative processes that allow building occupants to recover from physical and psychological stress, or to recover resources expended by focusing one's attention, and, consequently, to increase productivity and performance at the work place. Although there is a growing body of research into the human health impacts of bio-based material use, it is a nascent field that requires a strong interdisciplinary approach to research that includes designers, health professionals, ergonomists, material scientists, as well as user and manufacturer input.

In framing research questions and material and product design, it is helpful to keep in mind a framework that supplies goals for material use. REED is a design paradigm that can inspire designers to creatively utilise materials and seek products that solve design problems. It can help manufacturers develop new products and target material property changes. It can guide researchers towards identifying new methods and processes for altering material properties and help them to find interdisciplinary projects that expand the scope of expertise contributing to creating positive health impacts in the buildings we all spend so much of our time in.

As the science progresses, building certification schemes should include positive human (and environmental) impacts into their rating systems. It is past time that all stakeholders in the built environment turn their attention towards positive impacts for occupants, the environment, and society.

4 References

Asdrubali F (2006) Survey on The Acoustical Properties of New Sustainable Materials for Noise Control. In: Proceedings of Euronoise 2006. Tampere, Finland, pp 1–10

Attaianese E and Duca G (2012) Human factors and ergonomic principles in building design for life and work activities: an applied methodology. Theoretical Issues in Ergonomics Science 13(2): 187–202. DOI: 10.1080/1463922X.2010.504286.

Bhatta S, Kyttä M (2016) Sensory Experiences of Wood: Achieving The Energy Efficiency and User Satisfaction. In: Cronhjort Y, Hughes M, Sahi K, Tukiainen P (eds) Functional Wood. Aalto University, Helsinki, pp 96–99

Bulian F and Fragassa C (2016) VOC Emissions From Wood Products and Furniture: a Survey About Legislation, Standards and Measures Referred to Different Materials. FME Transactions, 44(4): 359.

Burnard MD, Nyrud AQ, Bysheim K, et al. (2015) Building material naturalness: Perceptions from Finland, Norway and Slovenia. Indoor and Built Environment 0(0): 1–16. DOI: 10.1177/1420326X15605162.

Burnard MD, Kutnar A (2015) Wood and human stress in the built indoor environment: a review. Wood Science and Technology 49:969–986. DOI: 10.1007/s00226-015-0747-3

Burnard MD, Schwarzkopf MJ, Kuntar A (2016) Interdisciplinary approaches to developing wood modification processes for sustainable building and beyond – INNORENEW COE. In: Proceedings of the World Conference on Timber Engineering, August 22-25, 2016. Vienna, Austria. Technical University of Vienna, Vienna, Austria.

Danna K and Griffin RW (1999) Health and Well-being in the Workplace: A Review and Synthesis of the Literature. Journal of Management 25(3): 357–384. DOI: 10.1177/014920639902500305

Derr V and Kellert SR (2013) Making children's environments 'R.E.D.': restorative environmental design and its relationship to sustainable design. In: Pavlides E and Wells J (eds), Proceedings of the 44th annual conference of the environmental design research association.

Dolan P, Foy C and Smith S (2016) The SALIENT Checklist: Gathering up the Ways in Which Built Environments Affect What We Do and How We Feel. Buildings 6(1): 9. DOI: 10.1177/014920639902500305

Dul J, Bruder R, Buckle P, Carayon P, Falzon P, Marras WS, Wilson JR, van der Doelen B (2012) A strategy for human factors/ergonomics: developing the discipline and profession. Ergonomics 55(4):377–95. DOI: 10.1080/00140139.2012.661087

Engvall K, Norrby C, Sandstedt E (2004) The Stockholm Indoor Environment Questionnaire: A sociologically based tool for the assessment of indoor environment and health in dwellings. Indoor Air, 14(1), 24-33. DOI: 10.1111/j.1600-0668.2004.00204.x

Environmental Protection Agency (EPA) (2016). Formaldehyde Emission Standards for Composite Wood Products. Docket Numbers: EPA-HQ-OPPT-2012-0018, EPA-HQ-OPPT-2011-0380

European Commission (EC) (1992). EN 120:1992 - Wood based panels. Determination of formaldehyde content. Extraction method called the perforator method.

Fell DR (2010) Restorative Properties of Wood in the Built Indoor. University of British Columbia.

Finnegan MJ, Pickering CA and Burge PS (1984) The sick building syndrome: prevalence studies. British medical journal (Clinical research ed.) 289(6458): 1573–1575. DOI: 10.1136/bmj.289.6458.1573

Gallego E, Roca X, Perales JF, et al. (2009) Determining indoor air quality and identifying the origin of odour episodes in indoor environments. Journal of Environmental Sciences 21(3): 333–339. DOI: 10.1016/S1001-0742(08)62273-1

Hartig T, Korpela K, Evans GW, Gärling T (1997) A measure of restorative quality in environments. Scandinavian Housing and Planning Research 14:175–194. DOI: 10.1080/02815739708730435

Hipp, J. A., & Ogunseitan, O. A. (2011). Effect of environmental conditions on perceived psychological restorativeness of coastal parks. Journal of Environmental Psychology, 31(4), 421-429. DOI: 10.1016/j.jenvp.2011.08.008

Huang J, Li K (2007) A New Soy Flour-Based Adhesive for Making Interior Type II Plywood. Journal of the American Oil Chemists' Society 85(1): 63-70. DOI:

10.1007/s11746-007-1162-1

Hug, S. M., Hartig, T., Hansmann, R., Seeland, K., & Hornung, R. (2009) Restorative qualities of indoor and outdoor exercise settings as predictors of exercise frequency. Health & place, *15*(4), 971-980. DOI: 10.1016/j.healthplace.2009.03.002

ISO/IEC (2006) ISO/IEC 14040:2006 Environmental management -- Life cycle assessment -- Principles and framework. Available from: http://www.iso.org/iso/catalogue_detail?csnumber=37456.

ISO (2005) ISO 7730:2005 Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Available from: http://www.iso.org/iso/catalogue_detail.htm?csnumber=39155

Jafarian H, Demers CMH, Blanchet P, Landry V (2016) Impact of Indoor Use of Wood on the Quality of Interior Ambiances under Overcast and Clear Skies : Case Study. BioResources 11:1647–1663. DOI: 10.15376/biores.11.1.1647-1663

Jang Y, Huang J, Li K (2011) A new formaldehyde-free wood adhesive from renewable materials. International Journal of Adhesion and Adhesives 31:754–759. DOI: 10.1016/j.ijadhadh.2011.07.003

Jensen LK, Larsen A, Mølhave L, et al. (2001) Health Evaluation of Volatile Organic Compound (VOC) Emissions from Wood and Wood-Based Materials. Archives of Environmental Health: An International Journal, JOUR, Routledge 56(5): 419–432. DOI: 10.1080/00039890109604477.

Kellert SR (2008) Dimensions, elements and attributes of biophilic design. 1st ed. In: Kellert SR, Heerwagen J, and Mador M (eds), Biophilic design: the theory, science and practice of bringing buildings to life, Hoboken: Wiley, pp. 3–19.

Kraniotis D, Langouet N, Orskaug T, Nore K, Glasø G (2016) Moisture buffering and latent heat sorption phenomena of a wood-based insulating sandwich panel. In: Proceedings of the World Conference on Timber Engineering, August 22-25, 2016. Vienna, Austria. Technical University of Vienna, Vienna, Austria.

Mang P and Reed B (2012) Designing from place: a regenerative framework and methodology. Building Research & Information 40(1): 23–38. DOI: 10.1080/09613218.2012.621341

Manninen A-M, Pasanen P and Holopainen JK (2002) Comparing the VOC emissions between air-dried and heat-treated Scots pine wood. Atmospheric Environment 36(11): 1763–1768. DOI: 10.1016/S1352-2310(02)00152-8

McCraty R, Atkinson M, Tomasino D, et al. (2009) The coherent heart: Heart-brain interactions, psychophysiological coherence, and the emergence of system-wide order. Integral Review 5(2): 10–115.

Mikhail A (1981) Stress: A Psychophysiological Conception. Journal of Human Stress 7(2): 9–15. DOI: 10.1080/0097840X.1981.9936821.

Milota MR (2000) Emissions from wood drying: The science and the issues. *Forest Products Journal* 50:10–20

Milota M, Mosher P, Li K (2007) VOC and HAP removal from dryer exhaust gas by absorption into ionic liquids. Forest Products Journal 57:73–77

Pasini M, Berto R, Brondino M, Hall R, Ortner C (2014) How to Measure the Restorative Quality of Environments: The PRS-11. Procedia – Social and Behavioral Sciences 159:293–297. DOI: 10.1016/j.sbspro.2014.12.375

Petrič M (2013) Surface Modification of Wood. Reviews Adhesives and Adhesion 1(2):216–247. DOI: 10.7569/RAA.2013.097308

Richardson, M., Maspero, M., Golightly, D., Sheffield, D., Staples, V., & Lumber, R. (2016). Nature: a new paradigm for well-being and ergonomics. *Ergonomics*, 1-14. DOI: 10.1080/00140139.2016.1157213

Sahlberg B, Gunnbjornsdottir M, Soon A, Jogi R, Gislason T, Wieslander G, Janson C, Norback D (2013) Airborne molds and bacteria, microbial volatile organic compounds (MVOC), plasticizers and formaldehyde in dwellings in three North European cities in relation to sick building syndrome (SBS). Science of the Total Environment 444:433–440. DOI: 10.1016/j.scitotenv.2012.10.114

Schwarzkopf M, Huang J, Li K (2010) A Formaldehyde-Free Soy-Based Adhesive for Making Oriented Strandboard. Journal of Adhesion 86:352–364. DOI: 10.1080/00218460903482549

Sinha A, Gupta R and Kutnar A (2013) Sustainable Development and Green Buildings. Drvna industrija 64(1): 45–53. DOI: 10.5552/drind.2013.1205

Terr AI (2009) Sick Building Syndrome: is mould the cause? Medical Mycology 47:S217–S222. DOI: 10.1080/13693780802510216

Tyrväinen L, Ojala A, Korpela K, Lanki T, Tsunetsugu Y, Kagawa T (2014) The influence of urban green environments on stress relief measures: A field experiment. Journal of Environmental Psycholology 38:1–9. DOI:

10.1016/j.jenvp.2013.12.005

Verma I (2016) Use of Wood in Elderly Care. In: Cronhjort Y, Hughes M, Paakkane M, Sahi K, Tukiainen P, Tulamo T, Vahtikari K (eds) Functional Wood. Helsinki, pp 70–73. ISBN: 978-952-60-6871-8

[WHO-E] World Health Organization Regional Office for Europe (2009). Who Guidelines for Indoor Air Quality: Dampness and Mould. World Health Organization. Copenhagen. 228 pages. DOI: 10.1186/2041-1480-2-S2-I1

Yu CWF, Kim JT (2012) Long-term Impact of Formaldehyde and VOC Emissions from Wood-based Products on Indoor Environments; and Issues with Recycled Products. Indoor Built Environment 21:137–149. DOI: 10.1177/1420326X11424330

Original Paper

Indoor and Built Environment

Indoor and Built Environment
0(0) 1–16

DOI: 10.1177/1420326X15605162
ibe.sagepub.com
SAGE

Building material naturalness: Perceptions from Finland, Norway and Slovenia

Michael D. Burnard[1,2], Anders Q. Nyrud[3], Kristian Bysheim[3], Andreja Kutnar[1,4], Katja Vahtikari[5] and Mark Hughes[5]

Abstract

Natural elements, life and life-like processes, as well as representations of them, can produce positive experiences within the built environment. Over the past decade, a number of empirical studies have found experiencing nature, both actively and passively, can reduce stress, increase human well-being, and produce positive emotional experiences. Therefore, in this study, user perceptions of building material naturalness in three European countries, Finland, Norway, and Slovenia were investigated. A survey was conducted in each country to gather user perceptions of the naturalness of 22 building materials. Perceptions were collected in three ways: a binary decision task (e.g. natural or not natural), a seven-point scale from not natural to natural, and an ordered ranking of all specimens from most natural to least natural. The building materials included solid wood, engineered wood-based products, masonry, stone, wallpaper, ceramic tiles, metal, and plastic. Solid wood, stone, and brick were clearly considered more natural than their counterparts with greater degrees of processing. Similarly, wood-based composites with greater degrees of processing were identified as being less natural than materials with less processing. Furthermore, the study found there was agreement between regions on building material naturalness, despite some minor differences.

Keywords

Building materials, Restorative environmental design, Regenerative design, User surveys, Built environment

Date received: 2 December 2014; accepted: 19 August 2015

Introduction

In Western cultures, naturalness is perceived positively and is a favoured trait in some product categories, such as food.[1,2] Building material naturalness has been identified as a positive trait in broader perception and preference studies.[3,4] Furthermore, building material naturalness may be an important aspect of the restorative environmental design (RED) and regenerative design paradigms, which emphasize a connection between building occupants and the natural environment in and around a building or location.[5,6]

Biophilic design and its implementation in wider design paradigms such as RED and regenerative design offer solutions to improve occupant well-being and improve attitudes and interactions with the natural

[1]Andrej Marušič Institute, University of Primorska, Koper, Slovenia
[2]Abelium, d.o.o., R&D, Ljubljana, Slovenia
[3]Norwegian Institute of Wood Technology, Oslo, Norway
[4]Faculty of Mathematics, Natural Sciences and Information Technology, University of Primorska, Koper, Slovenia
[5]School of Chemical Technology, Department of Forest Products Technology, Aalto University, Espoo, Finland

Corresponding author:
Michael D. Burnard, Andrej Marušič Institute, University of Primorska, Muzejski trg 2, Koper 6000, Slovenia.
Email: michael.burnard@iam.upr.si

environment. An important, yet not fully understood aspect of these design paradigms is the impact of building material selection on their successful implementation. To succeed, occupants must recognize design elements as natural at some level, and it is therefore important to know which materials potential occupants identify as natural to facilitate their connection to nature.

Material choices in building design

Evidence is growing that material choices may also produce positive effects on building occupants.[7–10] These positive health impacts should become important factors in material selection as more is learned about them. However, building material choices are often constrained by building code requirements (and therefore, the physical and structural properties of the building material), price, and availability.[7,11,12] Additionally, many building material choices are guided by a desire to minimize their negative impacts, either on the occupants or on the environment.[11,12] Given these constraints, designer intention and the material choices made to implement it are the key aspects of building material selection.[13] Indeed, Wastiels et al.[13], in their report on how architects select materials during the design process, describe that there is a strong correlation between the experience of a space and the materials that are used in that space. Consequently, when a designer's intentions are to reflect nature or natural elements, user perceptions of building material naturalness should be considered. Visual perception is a key factor in user perceptions of building materials, and users make very rapid assessments of the materials they encounter, further indicating the importance of appropriate material selection to meet designer intentions.[14] Material naturalness is likely to become an important indicator of both preference and healthful impact because of the positive influence on health associated with nature, especially in relation to restorative effects and recovery from stress.

Restorative effects

Restorative effects increase one's capacity to recover some depleted resource, such as the ability to focus one's attention or to recover from physical or psychological stress.[15–19] Natural areas, scenes, and environments have repeatedly been shown to have restorative effects on human subjects.[15–19] In some cases, even a view of nature through a window has provided restorative effects.[18] Furthermore, the presence of wooden furniture (e.g. desk, chairs, bookshelf, and window coverings) in office-like environments was found to reduce occupant stress during exposure to a stressor.[17] Restorative effects are important because they may allow one to work more productively or recover from injury or other physical stress more quickly, in addition to improving the general well-being of a population.[15,18] Therefore, designing buildings and environments to provide these effects should be an important goal for building designers. One way to achieve this goal is to include building elements that connect occupants to nature, such as views of nature, using natural materials, or including other life and life-like processes (e.g. flowing water, plant growth, or wood that ages over time) in the building.

RED, regenerative design

RED merges sustainable design practices with biophilic design and attempts to strengthen the bond between humans and nature.[6,20] Similarly, regenerative design embraces sustainable design while emphasizing the need to connect people to the place of a built environment so they are inspired by it and therefore motivated to care for it.[5,21,22] Mang and Reed[22] define *place* as a complex, multilayered and unique network within a geographic region that extends through time connecting natural ecology and culture. In order to connect people with nature in a given place, it is important that the materials and naturalness of that region are reflected in the built environment, for example, through building material use.

Both RED and regenerative design are extensions to current sustainable design practices. The objective of current sustainable design practices is to reduce the impact of building construction, location, and utilization on the environment by minimizing the impacts of material choice, site choice, and energy use across all phases of the building's lifetime (e.g. construction, occupancy).[12] One method to make nature more prominent in the built environment and move closer to the goals of RED and regenerative design is to implement biophilic design practices. These practices seek to incorporate the positive impacts of nature on building occupants by embracing the innate human attraction and connection to life and life-like processes.[23,24] To achieve this goal, biophilic design is organized around six major tenets which include (1) using environmental features such as views of nature, (2) including natural shapes and forms in the building design, (3) incorporating natural shapes and processes such as uncut stone, wood, or plants into the building, (4) including diverse light and space elements, (5) emphasizing place-based relationships with nature by using local materials and building traditions and (6) understanding the evolved human relationship with nature by recalling the early human relationship with nature, such as seeking shelter in forests.[20,23,25]

Previous studies on naturalness

Preferences for nature, natural settings, and natural products have been well studied both generally and specifically for building materials.[1–3,15,16,23,26–28] However, studies on perceptions of building material naturalness are limited. The studies that have examined building material naturalness directly have focused on the reasons for identifying the material as natural, or the underlying sensory input that causes an individual to identify a material as natural.[27,28] With the growing interest in green building paradigms, biophilic design, and healthy buildings, there is an emphasized need to incorporate natural materials and to know from potential occupants which materials are considered natural.

Fleming et al.[29] note that people are extremely good at identifying broad material classes such as wood, plastic, or soap and that the materials we encounter belong to a natural class such as stone or fabric. Fleming et al.[29] go farther, stating that humans make judgements about the perceived qualities of materials irrespective of the apparent class they fall within, but some material classes tend to be viewed as more natural than others. In one study, images of foliage, stone, water and wood were clearly considered more natural than images of fabric, glass, leather, metal, paper and plastic.[29]

According to the participants of a series of focus groups conducted in Oslo, Norway, the amount of processing a building material had been through and the presence of additives in building materials diminishes the material's perceived naturalness.[27] Similarly, Rozin found the transformations foodstuffs had undergone were an important aspect to user perceptions of their naturalness.[1,2] Overlivet and Soto-Faraco[28] believe the concept of naturalness is multidimensional and hard to attribute to a single characteristic such as the degree of transformation. This may indicate that there are cultural or place-based aspects to one's *assessment* of naturalness despite the homogeneity in *preference* for natural landscapes and nature that Kaplan and Herbert[26] have found across cultures.

Objectives

The objectives of this study were to understand user perceptions of building material naturalness. Of special interest was identifying the materials identified as most natural and least natural. These objectives were achieved by conducting surveys asking users to rate the naturalness of building materials. The surveys were conducted in three countries to determine if regional or cultural traditions, especially related to building and material use, influence user perceptions of building material naturalness.

Building and material use in Finland, Norway and Slovenia

Different regions utilize different building materials based on availability, needs, costs, local building tradition and regulations. Climatic and cultural differences (e.g. building traditions) in regions often lead to disparities in the style, methods and materials used in construction. Similarly, building styles often vary with population density, and therefore building styles in rural, suburban and urban areas are likely to differ as well. In all locations, efforts to improve building sustainability and energy efficiency may also impact building methods and styles. All three countries have abundant natural resources, especially forests and stone. The building styles are notably different between Slovenia's warmer sub-Mediterranean coastal region and its cooler interior. On the coastal region, stone houses and noticeable Italian influence dominate the building stock, while the interior regions of Slovenia vary in building style but heavily favour brick as the primary building material. The difference in building styles is less pronounced between Finland and Norway, as the two countries have a long intertwined history that has lead to many shared cultural elements, similar climates, and strong natural resource sectors to produce building materials.

The types and locations of homes in each country vary, as do their approaches to building material selection. Furthermore, each country has policies in place that impact building material decisions to some degree.

Finland.

As of 2012 in Finland, 54% of the dwellings were single-family homes (75% detached, 25% terraced and semi-attached), while 44% of dwellings were blocks of flats and 1.8% are categorized as other or unknown.[30]

As of 2006, the population in Finland was split into the following Nomenclature of Territorial Units for Statistics (NUTS) level 3 (NUTS-3) regions: 25% live in predominantly urban regions, 31% in intermediate regions and 44% in predominantly rural regions.[29] However, according to a 2011 survey ($n = 1620$), 23% of the surveyed population reported living in the countryside, 6% in areas that were 'neither clearly city nor countryside' and 71% in cities or towns.[31]

The National Building Code of Finland promotes energy-efficient construction and the use of renewable energy as well as reducing the carbon emissions.[32] Currently, legislation does not favour any material; however, city planning directives often regulate the material decisions for building exteriors.

Norway.

As of 2013, 59% of the dwelling stock (measured in m^2) in Norway was single and multifamily (less than four families), while 28% was multifamily/multistorey buildings, 10% was holiday homes, and 3% was classified as ‘other’.[33] In early 2013, 81% of the population in Norway lived in urban and suburban settlements, while the remaining 19% lived in rural areas.[33]

Norway has adopted environmental standards (Building Research Establishment Environmental Assessment Methodology, Norway), which have resulted in a higher demand for some wood products. National energy efficiency regulations have caused wall thickness to be increased to support greater quantities of insulation and have increased the demand for non-material-specific building components to achieve this.

Slovenia. As of 2002, brick dominated the Slovenian dwelling landscape, with approximately 60% of dwellings using it as the structural component of the house. Stone accounts for 12%, while concrete and wood account for 6% and 3%, respectively. The remaining 18% is attributed to ‘other’.[34] Most Slovenians (82%) live in single-family houses, while 7% live in row-type housing and 4% in multifamily buildings. The remaining 7% live in houses on agricultural land (e.g. farms).[34] As of 2006, the population in Slovenia was split into the following NUTS-3 regions: 25% live in predominantly urban regions, 31% in intermediate regions and 44% in predominantly rural regions.[34]

In 2008, Slovenia implemented a funding mechanism to provide loans for the construction or renovation of passive or low-energy homes, or to implement other energy efficiency measures (e.g. solar panels, biomass boilers, etc.).[35] In addition to these loans, the National Energy Efficiency Action Plan 2008–2016[35] provides subsidies for energy efficiency measures in Slovenia. These measures may shift building material usage in some buildings to favour renewable resource use. The preferred green building certification system in Slovenia is Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB).[35] Wood use in construction has been highlighted recently in Slovenia, and it is expected to increase in use both residentially and in industrial and business use.[36,37]

Materials and methods

Building material specimens were visually presented to respondents in three countries to gauge perceptions of building material naturalness in each location. Respondents were asked to complete a short questionnaire to assess the naturalness of each material in three ways: a binomial decision task, by assigning a seven-point rating and ranking the materials from most to least natural. Questionnaires were prepared in the native language of each country. Samples were convenience samples, and statistical analysis followed appropriate methodology for the data gathered.

Location selection

The locations were selected based on three factors: the proximity to the researchers' home institutions, the availability of respondents in the area, and the perceived similarities and dissimilarities culturally and in building styles. Within Slovenia, the survey was conducted in two places to investigate the possibility of discovering different perspectives in two culturally disparate areas of one country.

Specimen selection and preparation

Twenty-two types of building materials were selected to reflect a large cross section of materials used in European construction in various states of transformation, including wood, stone, brick, metal, plastic, and wood-based composites (Table 1). Some specimens were coated (e.g. painted) or polished. Each specimen was 100 mm × 100 mm and between approximately

Table 1. List of specimens used in the study.

Specimen ID	Specimen description
007	OSB
113	Pine, planed, knots
158	Particleboard
193	Cork
210	MDF (painted white)
235	Brick
292	Ceramic tile
307	Woven fabric
321	WPC, imitated growth rings
344	Pine, rough, clear of knots
401	MDF (painted white), imitated growth rings
420	Pine, planed, clear of knots
447	Steel, milled surface
469	Wool fabric
510	Stone tile
560	Painted pine
615	Ash HW, planed
642	Plastic, polished
712	MDF, plain
773	Steel (white)
823	Wallpaper, white
829	Leather, untreated

HW: heartwood; MDF: medium density fibreboard; OSB: oriented strand board; WPC: wood plastic composite.

Figure 1. A material specimen (ash heartwood, 615) as in a paperboard box.

Table 2. Respondent demographic summary.

	Finland	Norway	Slovenia			
Age group	Espoo	Oslo	Koper	Ljubljana	Combined	Total
15–25	18	32	22	35	57	107
26–35	16	18	12	4	16	50
36–45	2	4	5	2	7	13
46 +	3	2	1	–	1	6
No response	3	–	3	5	8	11
Sex						
Female	16	37	23	34	57	110
Male	24	19	17	9	26	69
No response	2	–	3	3	6	8
Total responses	42	56	43	45	88	186

10 mm and approximately 20 mm thick (some materials have variable thicknesses, such as the stone tile). Each sample was placed in the centre of a 115 mm × 115 mm paperboard box with a 45-mm lip. In this setting, the sides of the specimens were obscured, ensuring that the respondents judged only the surface of the material (Figure 1). Each specimen was labelled with a randomly selected number between 0 and 999 using the three-digit variation of that number (e.g. 7 was indicated as 007). Although a wide array of specimens have been included, there are some notable exclusions, e.g. rough pine with knots, which was excluded along with other materials to ensure respondents could manage the task of assessing all specimens. In this specific case, both rough pine and surfaced pine with knots were included to capture both aspects of the excluded wood specimen.

Questionnaire development

The questionnaire was originally designed to match the measurement methodology found in Overlivet and Soto-Faraco[28]; however, the free-modulus magnitude task was removed after testers consistently complained about the time necessary to complete the task, reported difficulties with it, or simply copied their ratings from another section. The resulting questionnaire had a total of four sections; the first three sections asked the respondents to rate all 22 materials in different ways, while the fourth asked for demographic information. The first section was a binary decision task and asked the respondent to simply choose if a material was natural or not natural by ticking the appropriate box for each sample. The second was a category scaling task, which partitioned the naturalness scale into seven points labelled 1 through 7, where 1 was 'not natural' and 7 was 'natural' and respondents were asked to rate each specimen on this scale. This task assumed respondents considered the relationship between points on the scale to be linear. Finally, the third section was a ranked ordering task, where respondents were asked to order all samples from most natural to least natural.

Questionnaire translations. Prior to being translated into Slovenian and Finnish, the questionnaire was translated from Norwegian to English. The Slovene and Finnish translations were completed in three parts: (1) a native speaker translated the questionnaire from English to the new language; (2) another native speaker translated from the new language to English and (3) a native English speaker then confirmed the translation accuracy.

Survey sampling and locations

The survey was conducted at four locations: Oslo (Norway), Espoo (Finland), Ljubljana (Slovenia), and Koper (Slovenia). In all locations, the samples were convenience samples. The survey was conducted in two locations in Slovenia to examine responses from two very different regions within the same country. Koper is a coastal city with a sub-Mediterranean climate and very different cultural identity (it is strongly influenced by Italy) to its counterpart in Ljubljana. In Ljubljana, the climate is subalpine.

In Oslo, the sample included members of a sports club aged 15 and older, and was 66% male (Table 2). In Espoo and Ljubljana, the samples were students, faculty, and staff of local universities (Aalto University and the University of Ljubljana, respectively). The respondents in Espoo were well balanced both in age and sex (Table 2). In Ljubljana, the respondents were younger than their counterparts in other regions, and there were more females (Table 2). In Koper, respondents were students, faculty, and staff of the University of Primorska and members of a local sports club. These respondents were well balanced in age and sex as well (Table 2).

Structure of the data

The response data to the first question were a collection of binomial responses (for natural or not natural) for each of the 22 building materials investigated. These responses were translated to '1' for natural and '0' for not natural. Responses to the second question yielded numerical ratings from 1 to 7 (not natural to natural) for each of the 22 building materials and were not normally distributed. The response data for the final question included ordinal rankings for all 22 items from most to least natural.

The number of responses considered in the analysis varied by specimen for the binary decision task and the scaled rating task. This is because, on occasion, respondents did not provide a response, or provided two responses on the same line, therefore making it impossible to discern their desired response. The number of responses used for analysis is provided in Table 3.

Only the complete responses to the ranking task were used in the analysis. Many respondents demonstrated difficulties completing this task accurately; the middle section of the rankings was often left blank, or in some cases had the same item listed multiple times. A list of the number of responses used in the analysis is provided in Table 4.

Responses for individual material specimens were considered to be independent for the first two questions, but not for the ranking task.

Comparisons were made between each location (city) where the survey was conducted and between country groups. When comparisons referencing just the location are made, the locations are referred to by their city name (e.g. Espoo, Koper, Ljubljana, Oslo). When comparisons are made between country groups, the two Slovenian groups (Koper, Ljubljana) are combined, and each location is referred by the country name (e.g. Finland, Norway, Slovenia).

Survey analysis methods

Data were manually transcribed from the paper questionnaires and imported into the statistical computing program R for further processing and analysis.[39] In R, the ggplot2, and plyr packages were used to analyse the data and create graphics.[39–41]

Binary decision task analysis. The binomial responses to the first question were analysed only with summary statistics. The total number of respondents per specimen and the percentage of respondents considering the material natural are reported for each group. Additionally, the percentage of all respondents, along with the total number of responses is reported.

Category scaling task analysis. Ratings were compared using pairwise Wilcoxon rank sum tests with Bonferroni adjustments for multiple comparisons. Means and 95% confidence intervals (CIs) were calculated for each country group to be graphically presented. Because ratings were bounded at 1 and 7, the 95% CIs were bounded when they exceeded these limits for graphical representation. The only specimen this procedure affected was stone tile; the 95% CI for the mean of the Norwegian group otherwise exceeds the maximum.

Ranked ordering task analysis. The ranked data were analysed with two rank correlation coefficients, Spearman's ρ and Kendall's τ. Spearman's rank correlation coefficient (Spearman's ρ), compares the sum of the squared differences in ranking between groups for each ranked item, and normalizes between -1 and 1. Kendall's τ is fundamentally different to Spearman's ρ in that it does not directly compare the difference between any two rankings. The coefficient compares the number of concordant pairs with the number of discordant pairs and normalizes between -1 and 1.

In both cases, a rank correlation coefficient of positive 1 describes perfect correlation, while a coefficient of negative 1 describes perfectly uncorrelated rankings.

Results

It was expected that there would be strong correlations between perceptions of naturalness between countries. Furthermore, materials having undergone greater degrees of transformation from their raw state were expected to be considered less natural than those closer to their raw state.

Responses to the binary decision task

Responses to the binary decision task indicate general agreement between all respondents (Table 5, Figure 2). Furthermore, the untreated wood specimens, along with stone tile were considered to be natural by more than 88% of all respondents. The specimens with

Table 3. Number of responses to questions 1 and 2 by specimen.

	Binary decision task (question 1)						Scaled rating task (question 2)					
				Slovenia						Slovenia		
Specimen	All Combined	Finland Espoo	Norway Oslo	Koper	Ljubljana	Combined	All Combined	Finland Espoo	Norway Oslo	Koper	Ljubljana	Combined
OSB	183	41	55	43	44	87	185	41	56	43	45	88
Knotty pine, planed	184	41	55	43	45	88	183	41	55	43	44	87
Particleboard	183	41	55	43	44	87	182	41	55	42	44	86
Cork	183	41	55	43	44	87	183	42	55	43	43	86
Painted MDF (white)	182	41	55	43	43	86	183	42	54	43	44	87
Brick tile	184	41	56	43	44	87	184	42	55	42	45	87
Ceramic tile, white	184	41	56	42	45	87	185	42	55	43	45	88
Woven fabric	183	40	56	43	44	87	184	42	55	43	44	87
WPC, growth rings	184	40	56	43	45	88	182	42	55	40	45	85
Clear pine, rough, sawn	184	41	56	42	45	87	185	42	55	43	45	88
MDF, growth rings, white	184	41	56	42	45	87	185	42	55	43	45	88
Clear pine, planed	184	41	56	43	44	87	185	42	55	43	45	88
Steel, milled surface	183	41	56	41	45	86	185	42	55	43	45	88
Woven wool fabric	185	41	56	43	45	88	184	42	55	43	44	87
Stone tile, untreated	185	41	56	43	45	88	182	41	54	43	44	87
Painted planed pine (white)	183	41	56	42	44	86	184	42	54	43	45	88
Ash HW, untreated	184	41	56	42	45	87	184	42	55	42	45	87
Plastic, polished	185	41	56	43	45	88	184	42	54	43	45	88
MDF, untreated	183	41	56	42	44	87	182	42	54	41	45	86
Steel, painted white	184	41	55	43	45	88	184	42	55	43	44	87
Wallpaper, white	185	41	56	43	45	88	185	42	55	43	45	87
Leather, untreated	182	38	56	43	45	88	184	41	55	43	45	87

HW: heartwood; MDF: medium density fibreboard; OSB: oriented strand board; WPC: wood plastic composite.

Table 4. Number of complete (useable) responses to the ranking task (question 3).

Location	n
Finland	
Espoo	32
Norway	
Oslo	17
Slovenia	
Koper	33
Ljubljana	29
Slovenia	62
Total	111

notably large divergences in ratings were particleboard, untreated medium density fibreboard (MDF), and the wood plastic composite (WPC) with imitated growth rings. Particleboard was considered natural by only 29.3% of respondents in Espoo, whereas 69.8%, 54.5%, and 50.9% of respondents found the material to be natural in Koper, Ljubljana, and Oslo, respectively. Similarly, less than 20% of respondents from Espoo found the untreated MDF sample to be natural, while more than 50% of respondents from other locations considered the specimen to be natural. The WPC with imitated growth rings was considered to be natural by only 25% or fewer respondents from Espoo and Oslo, while in both the Slovenian locations, the material was deemed to be natural by more than 45% of respondents (Table 5).

Table 5. Responses to the binomial decision task.

	All		Finland		Norway		Slovenia					
	Combined		Espoo		Oslo		Koper		Ljubljana		Combined	
Specimen	Natural (%)	n	Natural (%)	n	Natural (%)	n	Natural (%)	n	Natural (%)	n	Natural (%)	n
Knotty pine, planed	98.3	184	100	41	100	55	97.7	43	95.6	45	96.6	88
Clear pine, rough sawn	97.0	184	97.6	41	100	56	92.9	42	97.8	45	95.4	87
Clear pine, planed	92.7	184	97.6	41	96.4	56	86.0	43	90.9	44	88.5	87
Stone tile, untreated	89.2	185	90.2	41	96.4	56	81.4	43	88.9	45	85.2	88
Ash HW, untreated	88.0	184	87.8	41	87.5	56	85.7	42	91.1	45	88.5	87
OSB	76.1	184	65.9	41	80	55	79.1	43	79.5	44	79.3	87
Brick tile	75.7	183	78.0	41	73.2	56	69.8	43	81.8	44	75.9	87
Cork	54.5	183	46.3	41	63.6	55	51.2	43	56.8	44	54.0	87
MDF, growth rings, white	53.6	183	63.4	41	42.9	56	54.8	42	53.3	45	54.0	87
Particleboard	51.1	185	29.3	41	50.9	55	69.8	43	54.5	44	62.1	87
MDF, untreated	44.3	184	19.5	41	55.4	56	50.0	42	52.3	44	51.2	86
Woven wool fabric	41.6	183	31.7	41	46.4	56	39.5	43	48.9	45	44.3	88
Painted planed pine (white)	37.2	183	29.3	41	50	56	31.0	42	38.6	44	34.9	86
Leather, untreated	37.1	184	47.4	38	30.4	56	39.5	43	31.1	45	35.2	88
WPC, growth rings	36.5	182	25.0	40	23.2	56	51.2	43	46.7	45	48.9	88
Painted MDF (white)	27.3	185	17.1	41	25.5	55	41.9	43	23.3	43	32.6	86
Wallpaper, white	26.9	182	17.1	41	28.6	56	27.9	43	35.6	45	31.8	88
Ceramic tile, white	13.6	184	7.3	41	19.6	56	11.9	42	15.6	45	13.8	87
Steel, milled surface	9.2	183	7.3	41	5.4	56	7.3	41	4.4	45	5.8	86
Woven fabric	9.2	183	5.0	40	8.9	56	11.6	43	11.4	44	11.5	87
Plastic, polished	7.7	184	9.8	41	7.1	56	9.3	43	4.4	45	6.8	88
Steel, painted white	6.1	185	7.3	41	0	55	16.3	43	13.3	45	14.8	88

The presented percentage values are the percentage of respondents who deemed the sample to be natural and the *n*s are the number of respondents who completed the task for the specific specimen. HW: heartwood; MDF: medium density fibreboard; OSB: oriented strand board; WPC: wood plastic composite.

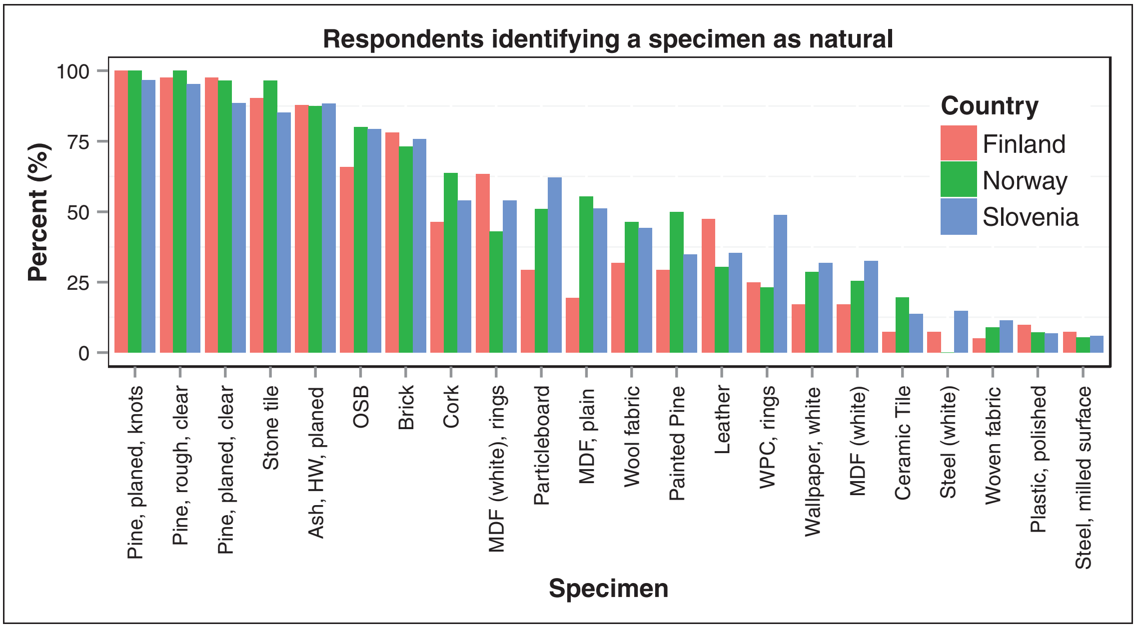


Figure 2. Comparison of responses to the binomial decision task by country.

Figure 3. The five materials perceived to be the most natural by all respondents according to the rating task. From left and in descending order: rough clear pine, planed knotty pine, planed clear pine, stone tile, and planed ash heartwood.

Rating building material naturalness

Ratings of building material naturalness coincided well with the binomial task decision. In general, there was agreement between respondent groups and the solid wood materials along with stone tile and brick tile were rated the most natural (Figures 3 and 4, Table 6). Similarly, the materials that were widely deemed not natural in the binary task decision were given low ratings; both steel specimens, the polished plastic specimen, the ceramic tile, and the woven fabric specimen were rated the lowest, and the fewest respondents considered them natural (Figures 4 and 5).

A complete list of mean ratings with 95% CIs is presented in Table 6. The amount of processing seemed to align with user ratings of naturalness for the wood-based products as well; particleboard, MDF, and WPC were all rated less natural than the solid wood specimens. However, oriented strand board (OSB), which has clearly recognizable wood components, yet has undergone significant processing, had a combined mean rating from all locations of 5.02 (7 was the 'most natural' rating), indicating it was considered to be fairly natural by most respondents.

The difference in mean ratings between countries was statistically significant for only five specimens (Table 7). None of the mean rating differences were statistically significant between Koper and Ljubljana, and only one mean rating difference was statistically significant between Finland and Norway (Table 7). The difference in mean ratings of only two materials exhibited strong statistical evidence. Particleboard was rated differently in Finland (mean: 3.44; 95% CI: 3.07–3.91) and Slovenia (mean: 4.41; 95%

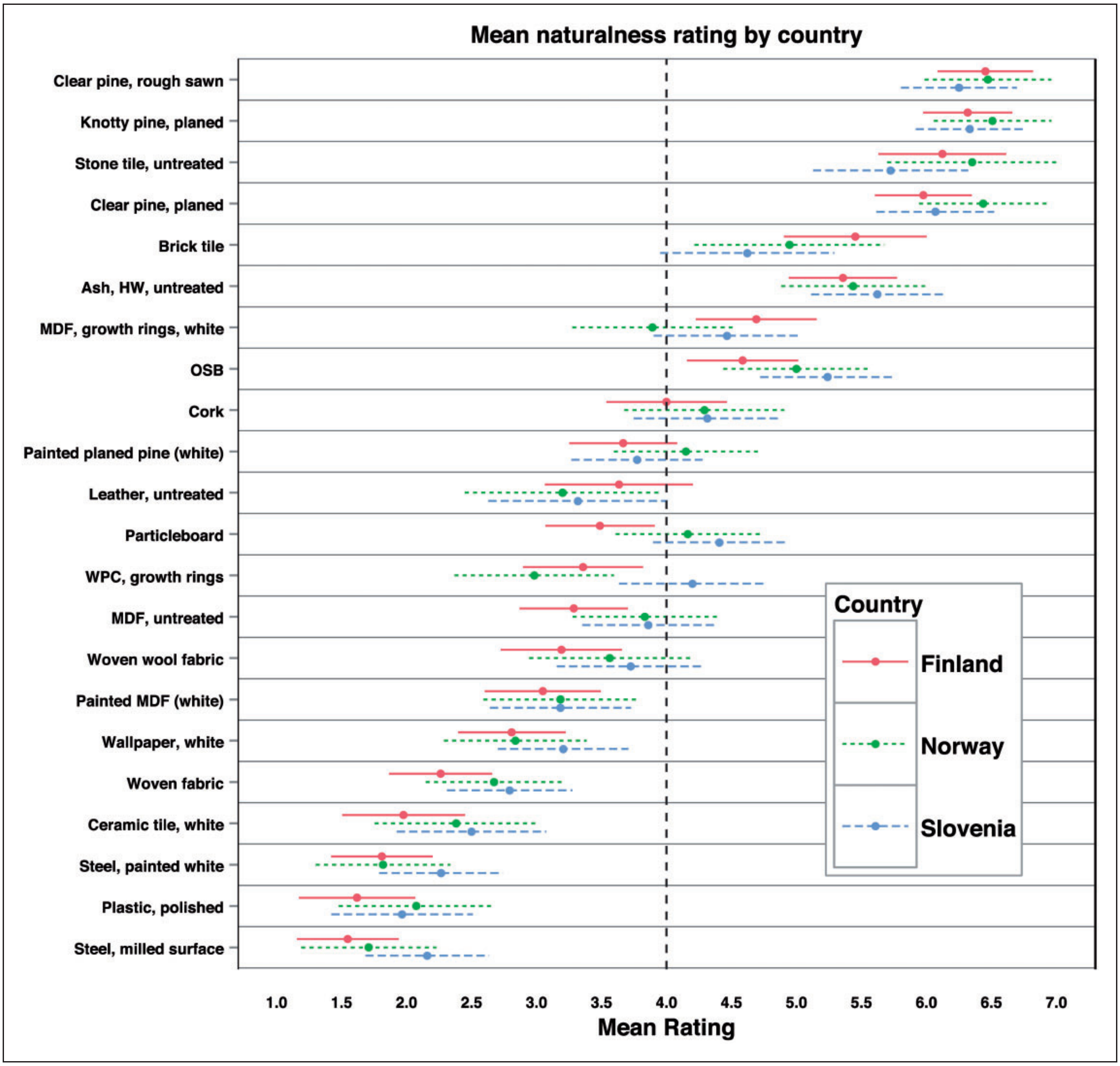


Figure 4. Mean ratings with 95% CIs (with Bonferroni adjustments) for each specimen, ordered by overall mean rating. CI: confidence interval.

CI: 3.90–4.92) (p value: 0.002) and the WPC with imitated growth rings was rated differently between the Norwegian (mean: 2.98; 95% CI: 2.37–3.59) and Slovenian (mean: 4.20; 95% CI: 3.63–4.77) groups (p value: >0.001). The difference in ratings for particleboard was also statistically significant between Finland (mean: 3.44; 95% CI: 3.07–3.91) and Norway (mean: 4.14; 95% CI: 3.61–4.72), though the evidence was only moderate (p value: 0.31). There was slight evidence (p value: 0.49) for a difference in ratings of the WPC with imitated growth rings between Finland (mean: 3.36; 95% CI: 2.90–3.82) and Slovenia (mean: 4.20: 95% CI: 3.63–4.77), as well. Brick tile was rated differently between Finland (mean: 5.45; 95% CI: 4.90–6.00) and Slovenia (mean: 4.62; 95% CI: 3.95–5.29) as well, though with only slight evidence (p value: 0.44). Untreated MDF was also rated differently between Finland (mean: 3.29; 95% CI: 2.87–3.70) and Slovenia (mean: 3.86; 95% CI: 3.35–4.37), with moderate evidence of the difference (p value: 0.23). Finally, there was slight evidence (p value: 0.48) of a difference in the ratings of the ash heartwood sample between Norway (mean: 5.62; 95% CI: 5.11–6.13) and Slovenia (mean: 4.62; 95% CI: 3.95–5.29).

The ratings for the wood, stone, plastic, metal, and leather coincide well with the material class ratings

Table 6. Mean rating with 95% CIs (including Bonferroni adjustments) and ordered by the combined rating of all respondents.

	All		Finland		Norway		Slovenia					
	Combined		Espoo		Oslo		Koper		Ljubljana		Combined	
Specimen	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Clear pine, rough sawn	6.40	6.22–6.58	6.45	6.08–6.82	6.25	5.80–6.70	6.25	5.65–6.68	6.47	5.82–6.85	6.47	5.98–6.96
Knotty pine, planed	6.38	6.22–6.54	6.32	5.97–6.66	6.33	5.92–6.75	6.33	5.71–6.66	6.51	6.00–6.95	6.51	6.06–6.96
Clear pine, planed	6.16	5.98–6.34	5.98	5.60–6.35	6.07	5.62–6.52	6.07	5.61–6.66	6.44	5.48–6.52	6.44	5.94–6.93
Stone tile, untreated	6.03	5.80–6.27	6.12	5.63–6.61	5.72	5.13–6.32	5.72	4.82–6.20	6.35	5.25–6.62	6.35	5.70–7.00
Ash HW, untreated	5.51	5.31–5.70	5.36	4.94–5.77	5.62	5.11–6.13	5.62	4.89–6.07	5.44	5.18–6.34	5.44	4.88–5.99
OSB	5.02	4.81–5.23	4.59	4.16–5.01	5.24	4.72–5.76	5.24	4.43–5.62	5.00	4.85–6.03	5.00	4.44–5.56
Brick tile	4.93	4.67–5.20	5.45	4.90–6.00	4.62	3.95–5.29	4.62	3.86–5.42	4.95	3.83–5.37	4.95	4.21–5.68
MDF, growth rings, white	4.35	4.12–4.58	4.69	4.23–5.15	4.47	3.90–5.03	4.47	3.51–4.81	3.89	4.11–5.40	3.89	3.28–4.50
Cork	4.23	4.02–4.45	4.00	3.54–4.46	4.31	3.75–4.88	4.31	3.79–5.10	4.29	3.53–4.84	4.29	3.67–4.91
Particleboard	4.13	3.92–4.33	3.49	3.07–3.91	4.41	3.90–4.92	4.41	3.93–5.12	4.16	3.71–4.88	4.16	3.61–4.72
Painted planed pine (white)	3.86	3.66–4.06	3.67	3.26–4.08	3.77	3.27–4.28	3.77	2.84–4.00	4.15	3.54–4.68	4.15	3.60–4.70
MDF, untreated	3.72	3.52–3.92	3.29	2.87–3.70	3.86	3.35–4.37	3.86	3.33–4.52	3.83	3.22–4.38	3.83	3.28–4.39
WPC, growth rings	3.64	3.40–3.88	3.36	2.90–3.82	4.20	3.63–4.77	4.20	3.29–4.61	2.98	3.78–5.06	2.98	2.37–3.59
Woven wool fabric	3.55	3.33–3.78	3.19	2.72–3.66	3.72	3.16–4.29	3.72	2.95–4.26	3.56	3.19–4.49	3.56	2.94–4.18
Leather, untreated	3.35	3.09–3.62	3.63	3.06–4.21	3.32	2.63–4.01	3.32	2.53–4.12	3.20	2.52–4.10	3.20	2.44–3.96
Painted MDF (white)	3.15	2.94–3.36	3.05	2.60–3.49	3.18	2.64–3.73	3.18	2.51–3.77	3.19	2.60–3.85	3.19	2.59–3.78
Wallpaper, white	3.01	2.81–3.20	2.81	2.40–3.22	3.20	2.70–3.71	3.20	2.51–3.68	2.84	2.74–3.89	2.84	2.29–3.39
Woven fabric	2.64	2.45–2.83	2.26	1.87–2.66	2.79	2.31–3.28	2.79	2.14–3.26	2.67	2.33–3.44	2.67	2.15–3.20
Ceramic tile, white	2.37	2.15–2.59	1.98	1.50–2.45	2.50	1.92–3.08	2.50	1.75–3.09	2.38	1.92–3.24	2.38	1.75–3.01
Steel, painted white	2.03	1.84–2.21	1.81	1.42–2.20	2.26	1.79–2.74	2.26	1.68–2.78	1.82	1.75–2.84	1.82	1.30–2.34
Plastic, polished	1.92	1.71–2.13	1.62	1.17–2.07	1.97	1.42–2.51	1.97	1.49–2.75	2.07	1.20–2.44	2.07	1.48–2.67
Steel, milled surface	1.89	1.70–2.07	1.55	1.15–1.94	2.16	1.68–2.64	2.16	1.59–2.69	1.71	1.63–2.72	1.71	1.19–2.23

CI: confidence interval; HW: heartwood; MDF: medium density fibreboard; OSB: oriented strand board; WPC: wood plastic composite.

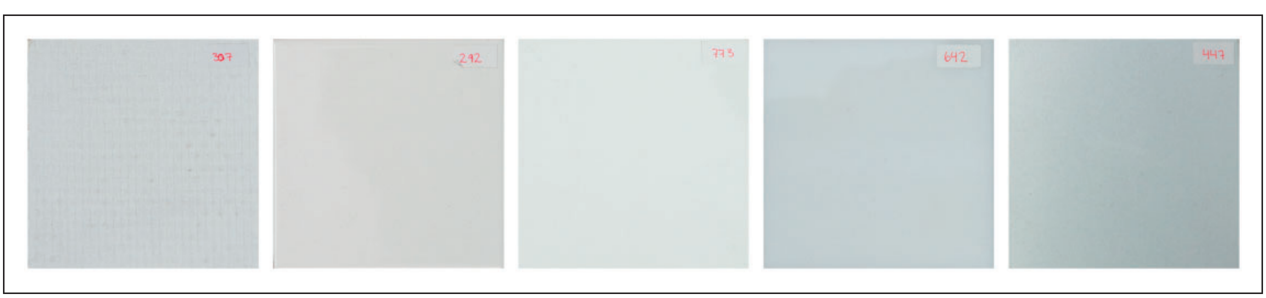


Figure 5. The five lowest rated building materials in descending order of perceived naturalness of all respondents. From left: woven fabric, ceramic tile, steel (white), plastic, and milled steel.

found in Fleming et al.,[29] where images of the wood and stone classes were rated as having high naturalness, leather was rated as having medium naturalness, and plastic and metal were rated as having low naturalness.

Ranking building material naturalness

The ranking task was clearly the most challenging task for respondents. Approximately 75% of respondents from Espoo, Koper, and Ljubljana completed the

Table 7. Specimens with statistically significant results (p value < 0.05, including Bonferroni adjustments), with p values derived from the Pairwise Wilcoxian Rank Sum test comparing countries and comparing Koper to Ljubljana within Slovenia.

Specimen	Koper–Ljubljana	Finland–Norway	Finland–Slovenia	Norway–Slovenia
Particleboard	–	0.031*	0.002**	–
Brick tile	–	–	0.044*	–
WPC, growth rings	–	–	0.049*	>0.001***
Ash heartwood	–	–	–	0.048*
MDF, untreated	–	–	0.023*	–

MDF: medium density fibreboard; WPC: wood plastic composite. *Significant at $p < 0.05$ level; **significant at $p < 0.01$ level; ***significant at $p < 0.001$ level.

Table 8. Correlation coefficients by group derived from responses to the ordinal rankings of all specimens from most natural to least natural (question 3).

Group	Kendall's τ	Spearman's ρ
Finland vs. Slovenia	0.758	0.905
Finland vs. Norway	0.746	0.862
Norway vs. Slovenia	0.694	0.900
Koper vs. Ljubljana	0.738	0.884

ranking task, while approximately 33% of the respondents from Oslo completed the task (Table 4). The difficulty respondents experienced with completing this task warrants some hesitation in attributing much significance to the outcome of the ranking task.

However, analysis of complete responses indicated strong correlations between all groups (Tables 8 and 9). Interestingly, both correlation coefficients indicate the strongest similarities in rankings were between Slovenia and Finland ($\tau = 0.758$, $\rho = 0.905$; Figure 6(a)). The weakest coefficients varied by measure. Spearman's ρ indicated the weakest correlation between Finland and Norway ($\rho = 0.862$; Figure 6(b)), while Kendall's τ indicated the weakest correlation between Slovenia and Norway ($\tau = 0.694$; Figure 7(a)). The comparison between regions in Slovenia indicated strong correlations ($\tau = 0.738$, $\rho = 0.884$; Figure 7(b)), but they were not as strong as some of the country correlations. In all cases, the correlation coefficients were strong, and similar, yet again indicating that, overall, respondents identify the solid wood, stone, and brick specimens as the most natural, while the more heavily processed (e.g. steel, plastic, ceramics) items were identified as being the least natural.

The combined rankings of all respondents indicated the five materials ranked as most natural were (in descending order of perceived naturalness) planed pine with knots, rough pine without knots, planed pine without knots, OSB, and stone tile (Table 9). The five ranked as least natural by the combined rankings of all respondents were (in descending order) white wallpaper, untreated leather, steel with a milled surface, polished plastic, and steel painted white (Table 9). The only material ranked identically between all groups was the planed pine with knots, and it was ranked as the most natural building material (Table 9). Knots interrupt the pattern of recognizable anatomical features in wood elements (e.g. grain pattern, rays, and figure) and are considered a defect structurally (knots reduce the mechanical properties of wood); however, the consistency of perceptions towards the pine specimen with knots may indicate that the interruption in the naturally occurring grain pattern is symbol of its authenticity as a natural material. The specimen with knots was planed and therefore processed more than the rough, clear pine specimen, yet was still ranked as being more natural.

Discussion and conclusions

Respondents consistently rated and ranked the materials with less apparent transformation (solid wood, stone, brick) as being more natural than materials with much greater degrees of transformation (metal, plastic, fabric). These views reflect previous findings related to foodstuffs as well as the building material naturalness findings of Nyrud et al.[1,2,27] The apparent amount of transformation may have affected user perceptions of naturalness even amongst the wood-based composite specimens. OSB was ranked and rated as more natural than particleboard, which was ranked and rated as more natural than MDF, each being more processed than the wood-based composite rated and ranked above it (Figure 8). However, the WPC specimens with imitated growth rings may have led some respondents to believe it was a minimally processed wood product. The WPC specimens have the most additives of all the wood-based materials presented and have undergone a great deal of transformation but were ranked higher than some wood-based composites with less transformation and fewer additives.

Table 9. Specimen naturalness rankings by group (1 is 'most natural', 22 is 'least natural') and ordered by the combined rankings from all respondents.

Specimen	All Combined	Finland Espoo	Norway Oslo	Slovenia Koper	Slovenia Ljubljana	Slovenia Combined
Pine, planed, knots	1	1	1	1	1	1
Pine, rough, clear	2	2	2.5	2	2	2
Pine, planed, clear	3	3	4	6	5	6
OSB	4	8	5	3	3	3
Stone tile	5	4	2.5	11	4	8.5
MDF (white), rings	6	5	10	5	6	4.5
Ash HW, planed	7	6	6	7	9	7
Particleboard	8	9	9	4	8	4.5
Cork	9	10	7	8	10	8.5
Brick	10	7	8	14	7	12
Painted pine	11	11	11	9	12.5	10
WPC, rings	12	12	16	10	11	11
MDF (white)	13	14	12	12	17	14
MDF, plain	14	15	14	17	14	15.5
Wool fabric	15	18	17	13	12.5	13
Ceramic tile	16	17	15	15	19	17
Woven fabric	17	20	13	18	18	19
Wallpaper, white	18	16	20	19	15	18
Leather	19	13	18	20	20	20
Steel, milled surface	20	19	21	16	16	15.5
Plastic, polished	21	22	19	21	22	21
Steel (white)	22	21	22	22	21	22

Ties in ranks are listed as half values for both tied materials (e.g. pine, clear, rough, and stone tile as 2.5 for Oslo). HW: heartwood; MDF: medium density fibreboard; OSB: oriented strand board; WPC: wood plastic composite.

While the initial expectation was to discover clear differences in perceptions of naturalness between country groups, and even between the two groups within Slovenia, this prediction was not borne out in the results. The differences between country groups were minor, with strong statistical evidence for only two materials: Finnish respondents rated particleboard as less natural than did Slovenian respondents, and Norwegian respondents rated the WPC sample with imitated growth rings lower than did Slovenian respondents. There were no significant differences between Slovenian respondents in Koper and Ljubljana. The differences detected seemed indicative of a knowledge gap related to familiarity with wood products rather than culturally different attitudes and perceptions of material naturalness.

In general, all respondents had a relatively strong degree of agreement on the naturalness of the 22 building materials presented for their assessment. Solid wood, stone, and brick tile were considered to be natural, while the items with greater degrees of processing were consistently regarded as being unnatural (e.g. steel, plastic, ceramics). The general agreement between each of the three measurement methods also provides a degree of self-validation of the results, which is important in this case because naturalness is not a precisely defined concept.[28] Therefore, it is clear that users understood the task and performed it accurately (with the possible exception of the ranking task).

Indeed, it was clear that the respondent's perceptions of naturalness were consistent when considering materials they clearly believed to be natural and those they did not (e.g. solid wood and steel, respectively). However, there seemed to be more ambiguity in their responses to materials they considered to have moderate naturalness, such as particleboard, MDF, and WPCs. Overall, OSB was rated as more natural than other composites (mean: 5.02; 95% CI: 4.81–5.23) and was ranked higher as well (fourth, higher than stone tile, brick, or ash heartwood). OSB has larger, more recognizable wood components than other wood-based composites and often has visible grain patterns in the strands, which may have contributed to its perception as highly natural.

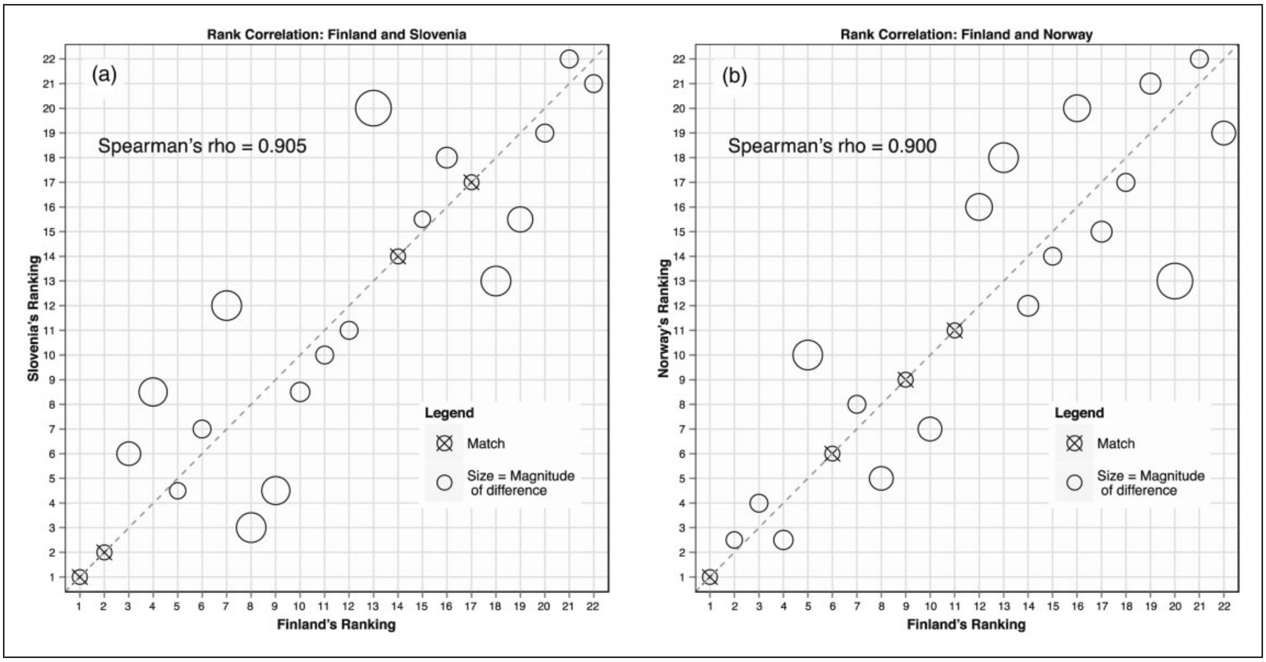


Figure 6. (a) Correlation of rankings between Slovenia and Finland. (b) Correlation of rankings between Norway and Finland. See Table 8 for a list of materials associated with each ranking.

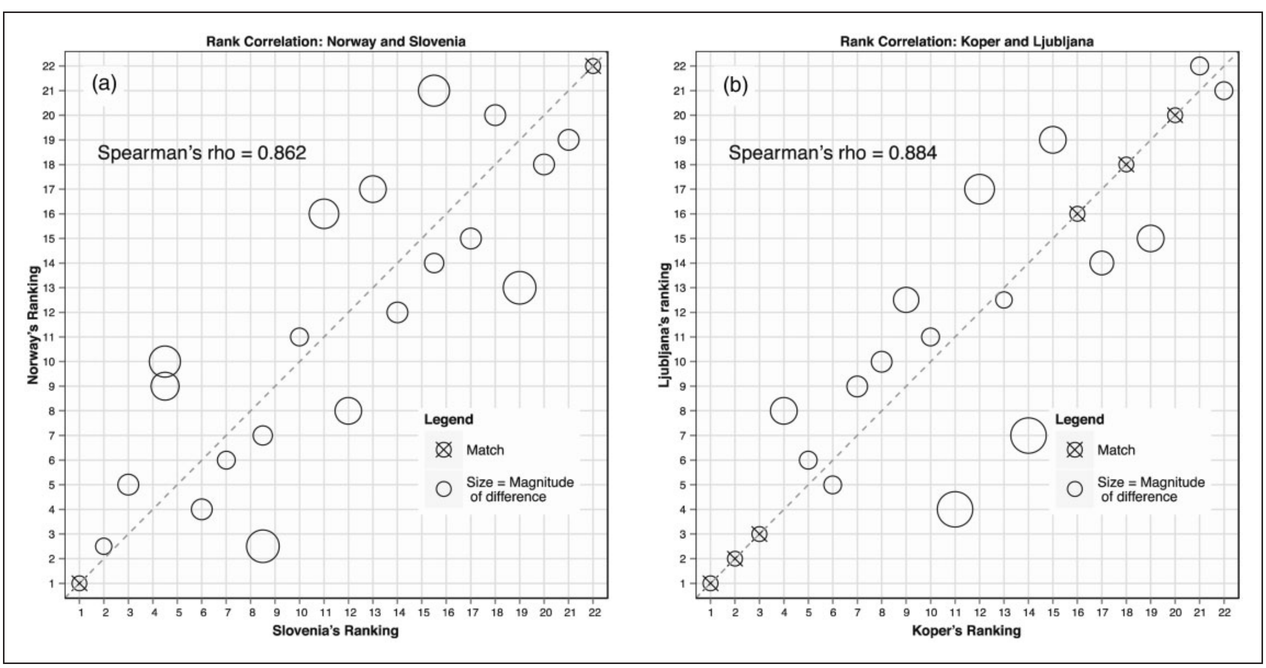


Figure 7. (a) Correlation of rankings between Ljubljana and Koper. (b) Correlation of rankings between Norway and Slovenia. See Table 8 for a list of materials associated with each ranking.

As architects and building designers make material decisions, especially when they seek to reflect experiences of nature, life, and life-like processes, they should consider user perceptions of building material naturalness. The apparent number of transformations and amount of additives may be more important than the actual transformations and additives present in a material. However, using materials closer to their raw state will likely ensure they are recognized as more natural than their heavily processed counterparts. The

Figure 8. Three wood-based composites presented, each with greater degrees of transformation from their original state. From left: OSB, particleboard, and MDF. MDF: medium density fibreboard; OSB: oriented strand board.

implications of material naturalness may also appear as designers implement RED or regenerative design. In these cases, material naturalness may have direct impacts on human health, worker productivity, and learning.

To maximize the positive impacts on building occupants, further research must examine the source of restorative effects in the built environment and identify the most suitable design solutions for implementing them. Experiments gauging occupant responses to stress, stress recovery, attention restoration, and other indicators of wellbeing should focus specifically on the environment in which occupants spend most of their time. An emphasis on the types of materials and how they are used in the built environment in these studies will provide designers with a stronger foundation for designing healthy environments and provide the society with healthier buildings. Furthermore, replicating this study in other locations and focusing on subsets of material classes (e.g. wood) with more varieties within the class will further illuminate trends in people's perceptions of building material naturalness.

Authors' contribution

All authors contributed equally in the preparation of this manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgements

This article is based upon work from COST Action FP1303, supported by COST (European Cooperation in Science and Technology) and the authors would like to acknowledge the financial support from the Aalto University Aalto Energy Efficiency Research Program (AEF).

References

1. Rozin P. The meaning of ''Natural'': process more important than content. *Psychol Sci* 2005; 16(8): 652–658.
2. Rozin P, Fischler C and Shields-Agrelès C. European and American perspectives on the meaning of natural. *Appetite* 2012; 59(2): 448–455.
3. Jonsson R. The end consumer's choice of floorcovering in the Netherlands and the United Kingdom: a comparative pilot study of substitute competition. *Jpn J Wood Sci* 2005; 51(2): 154–160.
4. Rice J, Kozak RA, Meitner MJ and Cohen DH. Appearance wood products and psychological well-being. *Wood Fib Sci* 2006; 38(4): 644–659.
5. Cole RJ. Regenerative design and development: current theory and practice. *Buil Res Inf* 2012; 40(1): 1–6.
6. Derr V and Kellert SR. Making children's environments ''R.E.D'': restorative environmental design and its relationship to sustainable design. In Pavlides E and Wells J (eds) *Proceedings of the 44th annual conference of the Environmental Design Research Association*. Providence, Rhode Island. May 29–June 1 2013; pp. 31–37.
7. Fell D. *Wood in the human environment: restorative properties of wood in the built indoor environment*. Vancouver: University of British Columbia, 2010.
8. Sakuragawa S, Miyazaki Y, Kaneko T and Makita T. Influence of wood wall panels on physiological and psychological responses. *J Wood Sci* 2005; 51(2): 136–140.
9. Tsunetsugu Y, Miyazaki Y and Sato H. The visual effects of wooden interiors in actual-size living rooms on the autonomic nervous activities. *J Physiol Anthropol* 2002; 21(6): 297–300.
10. Tsunetsugu Y, Miyazaki Y and Sato H. Physiological effects in humans induced by the visual stimulation of room interiors with different wood quantities. *J Wood Sci* 2007; 53: 11–16.
11. O'Connor J, Kozak R, Gaston C and Fell D. Wood in nonresidential buildings: opportunities and barriers. *Forest Prod J* 2004; 54(3): 19–28.
12. Sinha A, Gupta RK and Kutnar A. Održivi razvoj i zelena gradnja [Sustainable development and green buildings]. *Drvna Industrija* 2013; 64(1): 45–53.
13. Wastiels L, Wouters I and Lindekens J. Material knowledge for design – the architect's vocabulary. In Poggenpohl S (ed.) *Proceedings of international association of societies of design research,* November 12–15, 2007; Hong Kong: Hong Kong Polytechnic University: 1–16.

14. Wastiels L, Schifferstein HNJ, Wouters I and Heylighen A. Touching materials visually: about the dominance of vision in building material assessment. *Int J Des* 2013; 7(2): 31–41.
15. Kaplan R and Kaplan S. *The experience of nature: a psychological perspective*. Cambridge, UK: Cambridge University Press, 1989.
16. Kaplan S. The restorative benefits of nature: toward an integrative framework. *J Environ Psychol* 1995; 15(3): 169–182.
17. Tyrväinen L, Ojala A, Korpela K, Lanki T, Tsunetsugu Y and Kagawa T. The influence of urgan green environments on stress relief measures: a field experiment. *J Environ Psychol* 2014; 38: 1–9.
18. Ulrich R. View through a window may influence recovery from surgery. *Science* 1984; 224(4647): 420–421.
19. Ulrich R, Simons R, Losito B, Fiorito E, Miles M and Zelson M. Stress recovery during exposure to natural and urban environments. *J Environ Psychol* 1991; 11: 201–230.
20. Kellert SR. Dimensions, elements and attributes of biophilic design. In: Kellert RS, Heerwagen JH and Mador ML (eds) *Biophilic design: the theory, science and practice of bringing buildings to life*. 1st ed. Hoboken, NJ: John Wiley & Sons, 2008, pp.3–19.
21. Mang N. *Toward a regenerative psychology of urban planning*. Doctoral Dissertation, Saybrook Graduate School and Research Center, San Francisco, CA, 2009.
22. Mang P and Reed B. Designing from place: a regenerative framework and methodology. *Buil Res Inf* 2012; 40(1): 23–38.
23. Kellert SR. *Building for life: designing and understanding the human–nature connection*. 1st ed. Washington, DC: Island Press, 2005.
24. Wilson A. Biophilia in practice: buildings that connect people with nature. In: Kellert SR, Heerwagen JH and Mador ML (eds) *Biophilic design: the theory, science and practice of bringing buildings to life*. 1st ed. Hoboken, NJ: John Wiley & Sons, 2008, pp.325–333.
25. Kellert SR, Heerwagen JH and Mador ML (eds). *Biophilic design: the theory, science and practice of bringing buildings to life*. 1st ed. Hoboken, NJ: John Wiley & Sons, 2008.
26. Kaplan R and Herbert E. Cultural and subcultural comparisons in preferences for natural settings. *Landsc Urban Plan* 1987; 14: 281–293.
27. Nyrud AQ, Clementz CA, Steiner Y, Bysheim K and Arnseth JH. *Correlation between building material naturalness and perception of indoor environments [Sammenhengen mellom byggematerialer og folks opplevelser av innemiljø]*. Technical Report. Rapport 8. 2010. Oslo: Norwegian Institute of Wood Technology.
28. Overlivet KE and Soto-Faraco S. I can't believe this isn't wood! An investigation in the perception of naturalness. *Acta Psychol* 2011; 136(1): 95–111.
29. Fleming RW, Wiebel C and Gegenfurtner K. Perceptual qualities and material classes. *J Vis* 2013; 13(8): 1–20.
30. Statistics Finland. *Construction and Housing Yearbook 2013, Official Statistics of Finland*. Helsinki: Statistics Finland, 2014.
31. Sitra, The Finnish Innovation Fund. Landmark-barometer [Maamerkit-barometri], http://www.sitra.fi/artikkelit/maaseutu/maaseutu-ja-yhdyskuntarakenne (accessed 14 July 2014).
32. Ministry of the Environment. *National building code of Finland*. Helsinki, Finland: Ministry of the Environment, 2013.
33. Statistics Norway. Statistics Norway [Online] Oslo: Statistics Norway, http://ssb.no/en/bygg-bolig-og-eiendom/statistikker/boligstat (accessed 28 July 2014).
34. Statistical Office of the Republic of Slovenia [SURS]. Statistical Office of the Republic of Slovenia [Online] http://pxweb.stat.si/pxweb/Database/Census2002/Census2002.asp#2007e (accessed 16 May 2014).
35. National Energy Efficiency Action Plan 2008–2016. Republic of Slovenia, 2008.
36. Kitek Kuzman M and Kutnar A. *Contemporary Slovenian timber architecture for sustainability*. Cham [etc.]: Springer, 2014.
37. Kitek Kuzman M. *Wood in contemporary Slovenian architecture*. Ljubljana, Slovenia: University of Ljubljana, 2010.
38. Kušar J. Foreward. In: Kitek-Kuzman M (ed.) *Wood in contemporary Slovenian architecture*. Ljubljana, Slovenia: University of Ljubljana, 2010, p.19.
39. R Core Team. *R: A language and environment for statistical computing*. Report No.: 3-900051-07-0. Vienna, Austria: R Foundation for Statistical Computing, 2013.
40. Wickham H. The split–apply–combine strategy for data analysis. *Stat Soft* 2011; 40(1): 1–29.
41. Wickham H. *ggplot2: elegant graphics for data analysis*. 1st ed. New York: Springer, 2009.

INVESTIGATION OF MATERIALS

The study consists of three parts, all of which are required, plus one short section covering demographics.

You will be presented with different types of materials and asked to assess their naturalness in different ways.

1 Natural / not natural

Please consider whether the material specimens being shown are natural or not natural by evaluating each specimen visually. Consider the various specimens for only a few seconds each, and tick the answer that you think is appropriate.

Sample ID	Natural	Not natural
007	☐	☐
113	☐	☐
158	☐	☐
193	☐	☐
210	☐	☐
235	☐	☐
292	☐	☐
307	☐	☐
321	☐	☐
344	☐	☐
401	☐	☐
420	☐	☐
447	☐	☐
469	☐	☐
510	☐	☐
560	☐	☐
615	☐	☐
642	☐	☐
712	☐	☐
773	☐	☐
823	☐	☐
829	☐	☐

2 The degree of naturalness

Please consider the extent to which you believe the various material samples are natural by evaluating each specimen visually.

For each of the various material samples circle the number that best represents your perception of the material. Do not evaluate each sample for a long time, but select the answer that you think is correct immediately.

Sample ID	***1 = Not natural***						***7 = Natural***
007	1	2	3	4	5	6	7
113	1	2	3	4	5	6	7
158	1	2	3	4	5	6	7
193	1	2	3	4	5	6	7
210	1	2	3	4	5	6	7
235	1	2	3	4	5	6	7
292	1	2	3	4	5	6	7
307	1	2	3	4	5	6	7
321	1	2	3	4	5	6	7
344	1	2	3	4	5	6	7
401	1	2	3	4	5	6	7
420	1	2	3	4	5	6	7
447	1	2	3	4	5	6	7
469	1	2	3	4	5	6	7
510	1	2	3	4	5	6	7
560	1	2	3	4	5	6	7
615	1	2	3	4	5	6	7
642	1	2	3	4	5	6	7
712	1	2	3	4	5	6	7
773	1	2	3	4	5	6	7
823	1	2	3	4	5	6	7
829	1	2	3	4	5	6	7

3 Ranking of material samples

Please rank all samples in relation to your assessment of the naturalness of each sample. Write down the sample number for the sample material you feel is **most natural in the first line**, and write the sample number for each other sample in order of decreasing naturalness.

Rank	***Sample ID***
Most natural **1**	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
Least natural **22**	

4. Demographic questions

Age		
Gender	☐**Female**	☐**Male**

MATERIAALITUTKIMUS

Tutkimukseen kuuluu neljä osa-aluetta ja lisäksi lyhyt taustatietokartoitus. Kaikkiin kysymyksiin tulee vastata.

Sinulle näytetään erityyppisiä materiaaleja, minkä jälkeen sinun tulee arvioida niiden luonnollisuutta eri tavoin.

1 Luonnollinen / ei-luonnollinen

Arvioi, ovatko näkemäsi materiaalinäytteet luonnollisia vai ei-luonnollisia. Arviointi tapahtuu katsomalla kutakin näytettä. Katso kutakin näytettä muutaman sekunnin ajan ja merkitse vastauksesi kyseisen näytteen kohdalle.

Näytteen nro	Luonnollinen	Ei-luonnollinen
007	☐	☐
113	☐	☐
158	☐	☐
193	☐	☐
210	☐	☐
235	☐	☐
292	☐	☐
307	☐	☐
321	☐	☐
344	☐	☐
401	☐	☐
420	☐	☐
447	☐	☐
469	☐	☐
510	☐	☐
560	☐	☐
615	☐	☐
642	☐	☐
712	☐	☐
773	☐	☐
823	☐	☐
829	☐	☐

2 Luonnollisuuden aste

Arvioi kuinka luonnollinen kukin materiaalinäyte mielestäsi on. Arviointi tapahtuu katsomalla näytteitä.

Ympyröi kunkin materiaalinäytteen kohdalta numero, joka vastaa näkemystäsi sen luonnollisuudesta. Älä käytä arviointiin liian pitkää aikaan, vaan valitse vastaus joka ensimmäisenä tuntuu oikealta.

Näytteen nro	*1 = Ei-luonnollinen*				*7 = Luonnollinen*		
007	1	2	3	4	5	6	7
113	1	2	3	4	5	6	7
158	1	2	3	4	5	6	7
193	1	2	3	4	5	6	7
210	1	2	3	4	5	6	7
235	1	2	3	4	5	6	7
292	1	2	3	4	5	6	7
307	1	2	3	4	5	6	7
321	1	2	3	4	5	6	7
344	1	2	3	4	5	6	7
401	1	2	3	4	5	6	7
420	1	2	3	4	5	6	7
447	1	2	3	4	5	6	7
469	1	2	3	4	5	6	7
510	1	2	3	4	5	6	7
560	1	2	3	4	5	6	7
615	1	2	3	4	5	6	7
642	1	2	3	4	5	6	7
712	1	2	3	4	5	6	7
773	1	2	3	4	5	6	7
823	1	2	3	4	5	6	7
829	1	2	3	4	5	6	7

3 Materiaalinäytteiden asettaminen järjestykseen luonnollisuuden mukaan

Järjestä materiaalinäytteet aiemmin tekemäsi luonnollisuusarvion mukaiseen järjestykseen. Merkitse mielestäsi **luonnollisimman** materiaalinäytteen numero **ensimmäiselle riville** ja merkitse sen jälkeen muiden näytteiden numerot järjestyksessä niin, että viimeisellä rivillä on vähiten luonnollisen näytteen numero.

Arvio	***Näytteen nro***
Luonnollisin **1**	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
Vähiten luonnollinen **22**	

4. Taustatiedot

Ikä		
Sukupuoli	☐ **Nainen**	☐ **Mies**

Preiskava materialov

Raziskava je sestavljena iz 4 delov ter dodatnega kratkega dela, ki se nanaša na demografske podatke. Prosimo, da odgovorite na vprašanja v vseh petih delih raziskave.

Predstavili vam bomo različne vrste materialov in vas prosili, da na različne načine ocenite njihovo naravnost.

1 Naraven / nenaraven

Prosimo, da vizualno ocenite, ali je vzorec materiala, ki vam ga bomo pokazali, naraven ali nenaraven. Vsak vzorec vrednotite le nekaj sekund in nato označite odgovor, ki se vam zdi primeren.

Številka vzorca	Naraven	Nenaraven
007	☐	☐
113	☐	☐
158	☐	☐
193	☐	☐
210	☐	☐
235	☐	☐
292	☐	☐
307	☐	☐
321	☐	☐
344	☐	☐
401	☐	☐
420	☐	☐
447	☐	☐
469	☐	☐
510	☐	☐
560	☐	☐
615	☐	☐
642	☐	☐

712	☐	☐
773	☐	☐
823	☐	☐
829	☐	☐

2 Stopnja naravnosti

Prosimo, vizualno ocenite, v kolikšni meri menite, da so različni vzorci materiala naravni.

Za vsakega od različnih vzorcev materiala obkrožite številko, ki najbolje predstavlja vaše dojemanje materiala. Prosimo, da vsak vzorec ocenjujete le kratek čas, ter takoj ob pogledu nanj izberete odgovor, za katerega mislite, da je pravilen.

Številka vzorca	***1 = ni naraven***						***7 = Naraven***
007	1	2	3	4	5	6	7
113	1	2	3	4	5	6	7
158	1	2	3	4	5	6	7
193	1	2	3	4	5	6	7
210	1	2	3	4	5	6	7
235	1	2	3	4	5	6	7
292	1	2	3	4	5	6	7
307	1	2	3	4	5	6	7
321	1	2	3	4	5	6	7
344	1	2	3	4	5	6	7
401	1	2	3	4	5	6	7
420	1	2	3	4	5	6	7
447	1	2	3	4	5	6	7
469	1	2	3	4	5	6	7
510	1	2	3	4	5	6	7
560	1	2	3	4	5	6	7
615	1	2	3	4	5	6	7
642	1	2	3	4	5	6	7
712	1	2	3	4	5	6	7
773	1	2	3	4	5	6	7
823	1	2	3	4	5	6	7
829	1	2	3	4	5	6	7

3 Skupna ocena naravnosti

Prosimo, da z vizualnim vrednotenjem vsakega vzorca samostojno (brez vnaprejšnje številčne sugestije) ocenite, v kolikšni meri so različni vzorci materiala naravni ali nenaravni.

Za začetek izberite kateri koli vzorec in določite številčno vrednost, za katero mislite, da je primerna za vrednotenje njegove naravnosti. Potem dodelite vrednosti preostalim vzorcem v primerjavi z vrednostjo, ki ste jo dodelili prvemu vzorcu. Prosimo, navedite, ali ste opisni označbi "najbolj naravno" prisodili visoko ali nizko številko.

Številka vzorca	***Vrednost ocene naravnosti***
007	
113	
158	
193	
210	
235	
292	
307	
321	
344	
401	
420	
447	
469	
510	
560	
615	
642	
712	
773	
823	
829	

4. Razvrstitev vzorcev materialov

Razvrstite vzorce glede na vašo oceno njihove naravnosti. Zapišite številko vzorca za material, ki je po vašem mnenju najbolj naraven, v prvo vrstico. V naslednje vrstice vpišite številke vzorcev v padajočem redu glede na vašo oceno njihove naravnosti.

Uvrstitev	***Številka vzorca***
Najbolj naravno **1**	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
Najmanj naravno **22**	

5. Demografski podatki

Starost		
Spol	☐ **Ženska**	☐ **Moški**

Psychiatric Research Unit
WHO Collaborating Centre in Mental Health

WHO (Five) Well-Being Index (1998 version)

Please indicate for each of the five statements which is closest to how you have been feeling over the last two weeks. Notice that higher numbers mean better well-being.

Example: If you have felt cheerful and in good spirits more than half of the time during the last two weeks, put a tick in the box with the number 3 in the upper right corner.

	Over the last two weeks	All of the time	Most of the time	More than half of the time	Less than half of the time	Some of the time	At no time
1	**I have felt cheerful and in good spirits**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
2	**I have felt calm and relaxed**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
3	**I have felt active and vigorous**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
4	**I woke up feeling fresh and re-sted**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
5	**My daily life has been filled with things that interest me**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0

Informed Consent form for men and women participating in the Human stress in the Built Environment Experiment A

Principal Investigator: Dr. doc. Andreja Kutnar
Name of Organization: University of Primorska, Andrej Marušič Institute
Name of Proposal and version: Wood and Human Stress in the Built Indoor Environment (1)

This Informed Consent Form has two parts:

- **Information Sheet (to share information about the research with you)**
- **Certificate of Consent (for signatures if you agree to take part)**

You will be given a copy of the full Informed Consent Form

PART I: Information Sheet

Introduction

The University of Primorska Andrej Marušič Institute is conducting an experiment to determine how certain aspects of the built indoor environment affect human stress. We are interested to know if certain design decisions affect stress felt during stressful situations, and if those decisions affect how well an individual recovers from the stress. Today, you will be provided with information about the experiment, and asked to participate. You do not have to decide today whether or not you will participate. Before you decide, you can talk to anyone you feel comfortable with about the research.

We have made efforts to avoid technical language in this document, but we may have left some unfamiliar language in. Please ask any questions or for more information as you go through this form. You may also contact me at the provided e-mail address to ask further questions.

Purpose of the research
Stress is something all humans feel at some time or another. Your body reacts to stressful events in a variety of ways, and in some cases stress can lead to more serious health problems. We are interested to know how the environments people spend their time in affect the levels of stress they feel and how quickly they recover from stressful events. We are especially interested in design choices for the built indoor environment, because people spend approximately 85% of their time indoors. We are conducting this experiment to see how individuals react to and recover from a stressful event in several differently designed office-like environments to determine if and how certain design decisions influence stress and stress recovery.

Type of Research Intervention
During this experiment you will be asked to participate in two tests. Each test will be in a differently designed office-like room. You will be asked to provide saliva samples using a standard, non-invasive mouth swab seven times during each test (14 total). The test will last approximately 75 minutes total. Before and after the test you will be asked to fill out a short questionnaire relating to your mood. During the test, for a period of 5 minutes you will be asked to view discomforting images. These images cause most individuals to feel a small-to-medium amount of stress. No long-term effects are expected from this exposure. The stress event will occur early in the test and you will be provided time to recover from the event before the test is complete.

Participant selection
We have randomly selected individuals from the Primorska region to participate in this study, if they are non-smokers and have no stress-related diseases or conditions, have no heart related conditions, and are between the ages of 18 and 60. You have responded to our initial request for volunteers, and have been approved through the screening process. You are now being formally asked to provide your consent to participate in the research.

Voluntary Participation
Your participation in this research is entirely voluntary. It is your choice whether to participate or not. There will be no repercussions if you choose not to participate.

Procedures and Protocol
Once you have volunteered to participate in this study, two tests will be scheduled for different days. On each test day you will come to the test facility and take the test in a small, office-like room. The room will be different though similar each time. After you arrive the test will proceed as follows:

1. You will be asked to fill out a very brief questionnaire regarding your mood.
2. Directly after entering the test room you will provide a saliva sample. All saliva samples will be taken with a small non-invasive sampling device. This device is an absorbent device which you chew gently for approximately 1 minute. After

chewing the device you will place it in a container for storage. You will be assisted with this process if necessary.

3. You will then wear a heart rate monitor.
4. You will then sit for 15 minutes.
5. After 15 minutes a researcher will enter the room to take another saliva sample and begin the image display.
6. The researcher will return after the end of the image display and collect another saliva sample.
7. Thereafter you will be allowed to rest and recover from the stress event (image display). The research will enter the room 10, 20, 30, 45, and 60 minutes after the image display to collect saliva samples.

This test procedure will be repeated exactly when you return for the second test.

A. Unfamiliar Procedures

Providing saliva samples may be unfamiliar to you. It is as simple procedure and takes approximately one minute (60 seconds). Your saliva samples contain a specific hormone that is released when the body becomes stressed. The saliva samples will be assessed to determine how much of this hormone is present, and this will be used to determine how stressed you became, and how you recovered from the stress event. Your saliva samples will be used only for this study, and only to determine the amount of the stress related hormone present. After all results have been confirmed, the saliva samples will be destroyed.

Risks

This study will subject you to stress you may not encounter during your normal daily routine. However, the stress you will be subjected to is mild, and is considered to be within established safety parameters. Though people experience stress in different ways, the stress you'll be subjected to in this study is similar to what you may experience while watching a scary movie or action film.

Benefits

By participating in this study you will be contributing to creating a better understanding of how our environments affect the stress we feel in our daily lives and, importantly, how we recover from that stress. Stress can be harmful to the human body because excessive activation of the body's natural responses to stressful situations can lead to disease. Your contribution will help to improve our understanding how to minimize stress responses by designing the built environment to be more compatible and restorative for people.

Confidentiality

To ensure the anonymity and to protect your privacy, the test results will not be associated with any identifiable medical information. Records of your contact and personal information will be stored separately from your test results. Your tests results will be associated only with a number, not your name. This way, your personal information will be protected even from the researchers. This is a protection for you and aids in the protecting the integrity of the research as well.

Sharing the Results
Individual results will not be available from this study, however, the general results of the experiment will be made available to the test participants and the general public. The results will also be published in scientific journals and presented at scientific conferences. At no time during will your personal information be shared when reporting the results.

Right to Refuse or Withdraw
You do not have to take part in this research if you do not wish to do so. You may also stop participating in the research at any time you choose. It is your choice and all of your rights will still be respected.

Who to Contact
If you have any questions you may ask them now or later, even after the study has started. If you wish to ask questions later, you may contact any of the following: [name, address/telephone number/e-mail to be provided later]

This proposal has been reviewed and approved by KMERS, which is a committee whose task it is to make sure that research participants are protected from harm and that medical research is conducted ethically. If you wish to find about more about KMERS, contact [name, address, telephone number will be provided later].

You can ask me any more questions about any part of the research study, if you wish to.

PART II: Certificate of Consent

<u>Statement of the participant</u>

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research.

Print Name of Participant__________________

Signature of Participant ___________________

Date ___________________________

Day/month/year

<u>Statement by the researcher/person taking consent</u>

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands that the following will be done:

1. The volunteer will partake in two tests, each lasting approximately one hour and fifteen minutes (75 minutes).
2. The volunteer will provide seven (7) saliva samples per test (14 total).
3. The volunteer will view discomforting images as a stressor for a short period during each test.
4. The volunteer will complete short questionnaires relating their mood, and psychological state before and after the test period.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this ICF has been provided to the participant.

Print Name of Researcher/person taking the consent________________________

Signature of Researcher /person taking the consent__________________________

Date ___________________________

Day/month/year

Komisija Republike Slovenije za medicinsko etiko
dr. Božidar Voljč, dr. med., predsednik KME
Inštitut za klinično nevrofiziologijo
Klinični center
1525 Ljubljana

Univerza na Primorskem
Inštitut Andrej Marušič
Muzejski trg 2
6000 Koper
doc. dr. Andreja Kutnar, nosilec raziskave
e-pošta: andreja.kutnar@upr.si
tel.: 031 240 121

Koper, 06.11.2014

ZADEVA: VLOGA ZA SOGLASJE KOMISIJE K NAČRTOVANI RAZISKAVI

Spoštovani,

na vas se obračamo s prošnjo za soglasje za izvedbo raziskave z naslovom »Les in stres v grajenem notranjem okolju«, ki je del raziskav doktorske disertacije študenta Univerze na Primorskem, Fakultete za management, Michaela Davida Burnarda.
Namen raziskave je proučiti učinke rabe lesa kot materiala v notranjosti stavb, predvsem kot pohištvo, stenske obloge, talne obloge in v dekorativne namene, na stres. Raziskali bomo bistvene lastnosti lesa, za katere sklepamo, da naj bi prispevale k umirjanju stresa pri stanovalcih v grajenem bivalnem okolju, ter tako prispevali k razvoju znanosti na tem področju.

Lep pozdrav,

doc. dr. Andreja Kutnar
Andreja Kutnar

1. Poln naslov raziskave
Les in stres v grajenem notranjem okolju (ang. Wood and Human Stress in the Built Indoor Environment)
2. Odgovorni raziskovalec, nosilec in ustanova
• doc. dr. Andreja Kutnar, univ. dipl. inž. lesarstva (odgovorni raziskovalec in mentorica doktorskemu študentu, šifra SICRIS 31274) • Univerza na Primorskem, Inštitut Andrej Marušič, Muzejski trg 2, Koper (šifra SICRIS 1669)
3. Odgovorni zdravnik
Pri raziskavi bo sodelovala psihologinja, dr. Vita Poštuvan, univ. dipl. psih. (EuroPsy) (šifra SICRIS 28757).
4. Načrt in protokol raziskave
Raziskavo bomo izvedli v štirih fazah: 1) vključitev oseb v raziskavo; 2) izvedba poskusov in reševanje kratkih vprašalnikov; 3) analiza podatkov; 4) razširjanje znanja. V prvi fazi bomo zajeli prostovoljce s Primorske, kjer bomo poskus tudi izvedli. V vabilu jih bomo seznanili z raziskavo in s tem, kakšne prostovoljce želimo v njo vključiti. V drugi fazi bomo pridobili njihove izjave o zavestni in svobodni privolitvi sodelujočih zdravih oseb, sodelujoča psihologinja bo izločila neustrezne prostovoljce, preko vprašalnika pa bomo pridobili informacije o zdravstvenem in psihičnem stanju v raziskavo zajetih oseb. Nato bomo izvedli poskus, ki bo za vsako osebo potekal v dveh delih (testih). V tretji fazi bomo z ustreznimi statističnimi in kvalitativnimi metodami obdelali in analizirali odvzete vzorce in pridobljene podatke. V tej fazi bomo podatke shranili v varni in hkrati dostopni podatkovni shrambi, tako da jih bomo lahko uporabljali tudi za primerjavo in nadaljnjo analizo. Takoj po zajetju bomo podatke anonimizirali in s tem zagotovili objektivnost analize (»slepa« analiza) ter anonimnost pri razširjanju rezultatov. Četrta faza raziskave vključuje razširjanje rezultatov z objavami znanstvenih člankov v recenziranih in indeksiranih znanstvenih revijah ter z udeležbami na tako domačih kot mednarodnih znanstvenih in strokovnih konferencah. <u>Protokol raziskave</u> Faza 1: V raziskavo bomo vključili naključno izbrane prostovoljce iz ciljne skupine na Primorskem. Ciljna skupina so nekadilci, stari med 20 in 60 let in sposobni podpisati izjavo o zavestni in svobodni privolitvi sodelujočih zdravih oseb. Potencialnim prostovoljcem bomo poslali vabilo, v katerem jim bomo predstavili temo raziskave (vendar ne specifičnega namena poskusa), opisali potek poskusa in jih podrobno seznanili s tem, kako bomo pridobljene podatke uporabili (anonimizirane znanstvene objave in predstavitve za industrijo) in varno hranili. Podrobno jih bomo seznanili s pravicami prostovoljca (da jim nikakor ni treba sodelovati, če ne želijo in da njihova zavrnitev zanje ne bo imela nikakršnih posledic itn.). V vabilu jih bomo tudi obvestili, da v raziskavo ne želimo vključiti kadilcev in ljudi, katerih zdravstveno ali psihološko stanje (npr. s stresom povezana stanja) bi lahko vplivalo na izid raziskave (v tej fazi bomo odločitev o tem prepustili potencialnim prostovoljcem). Faza 2: Prostovoljci bodo na kraj poskusa prišli sami. Tam jih bomo ponovno seznanili s protokolom izvedbe poskusa, po tem pa bodo jim bomo dali v podpis Izjavo o zavestni in svobodni privolitvi sodelujočih zdravih oseb. Po podpisu bodo prostovoljci opravili kratek klinični intervju s psihologinjo, ki bo izločila tiste, katerih zdravstvena ali psihološka stanja (npr. s stresom povezana stanja) bi lahko vplivala na izid raziskave, ali pa bi izpostavitev dodatnemu stresu lahko pomenila nepotrebno povečanje tveganja za poslabšanje njihovega zdravstvenega stanja (izključitveni kriterij bo prisotnost simptomov depresije, anksioznosti in

samomorilnega vedenja). Za poskus bomo izbrali 240 oseb. Prostovoljce bomo zaprosili, da nam povejo, če uporabljajo hormonske terapije ali zdravila (npr. kontracepcijska sredstva, kortikoidni steroidi, ipd.).
Prostovoljcem bomo dodelili naključno identifikacijsko številko, ki ne bo nikakor povezana z nobenim podatkom, ki bi omogočal povezavo s prej zbranimi osebnimi podatki (podrobnejši opis metode dodeljevanja identifikacijske številke opisan v podpoglavju »Načrt raziskave in metode dela« te točke). Poskus bo potekal v dveh delih, na različna dneva, vendar ob približno istem času, in sicer za vsakega prostovoljca v kontrolnem prostoru (v tem prostoru pri notranji opremi ne bomo uporabili lesa) ter v enem od prostorov, ki bodo na različne načine opremljeni z lesom (odslej: opremljeni prostor). Anonimna identifikacijska številka bo določala, v kateri naključno določen opremljeni prostor bo prostovoljec razvrščen in po kakšnem, naključno določenem, vrstnem redu bo opravil poskus (najprej v kontrolnem, potem v opremljenem prostoru ali obratno). Neposredno pred vstopom v prostor poskusa bomo prostovoljce prosili, da izpolnijo kratek vprašalnik o oceni psihičnega počutja (vprašalnik »WHO (pet) kazalec blaginje (različica 1998)« (glej prilogo)), nato pa jim bomo odvzeli prvi vzorec sline (podrobnejši opis poteka testa opisan v podpoglavju »Načrt raziskave in metode dela« te točke). Prostovoljci se bodo deset minut aklimatizirali na testni prostor, potem jim bomo odvzeli drugi vzorec sline. Po tem odvzemu jih bomo izpostavili rahlemu do zmernemu stresorju (gledali bodo zaporedje podob obrazov, ki izražajo jezo, in neprijetnih podob iz novic (npr. slike prometnih nesreč, prikazi nasilja, itd.), za katere je znano, da pri ljudeh povzročajo biološki stresni odziv). Takoj po koncu desetminutnega prikaza bomo prostovoljcem znova odvzeli vzorec sline ter vzorčenje ponavljali po 10, 20, 30, 45 in 60 minutah po prenehanju stresorja (prostovoljci bodo v tem času počivali/se umirjali). Po zadnjem odvzemu vzorca sline (po 60 minutah) bodo prostovoljci izpolnili kratek vprašalnik o svojem počutju med trajanjem poskusa ter o tem, kako udobno jim je bilo v testnem prostoru (modificiran vprašalnik »WHO (pet)«). Drugi del poskusa bomo izvedli po enakem postopku, le da bo potekal v drugem, v naprej določenem prostoru (v kontrolnem ali opremljenem prostoru, glede na vnaprejšnjo naključno dodelitev). Po opravljenem drugem delu poskusa bomo prostovoljcem, če bodo tako želeli, podrobneje predstavili tematiko raziskave.

Faza 3: Odvzete vzorce sline bomo shranili po specifikacijah dobavitelja kita za vzorčenje (ti bodo natančno znani po izboru dobavitelja) in jih poslali na analizo v ustanovo, ki takšne analize opravlja kot standardizirano tržno dejavnost. Zaradi zagotavljanja zasebnosti prostovoljcev bodo vzorci anonimni in označeni le s črtno kodo in pripadajočo identifikacijsko številko. Dobljene podatke bomo obdelali s primernimi statističnimi metodami in ugotavljali, ali je kateri od dejavnikov v poskusu primarno ali posredno (v interakciji z drugimi dejavniki) vplival na stresni odziv in njegovo umirjanje pri prostovoljcih. Podatki bodo dolgoročno hranjeni v varni, trajni, vendar pooblaščenim raziskovalcem dostopni podatkovni shrambi.

Faza 4: Poglavitna metoda razširjanja znanja bo objava recenziranih znanstvenih člankov v indeksiranih revijah ter predstavitve na znanstvenih konferencah (objava v zbornikih konferenc). Objavili bomo tudi strokovne članke, s katerimi bomo o rezultatih raziskave seznanili tudi širšo javnost. Tudi na spletni strani Inštituta Andrej Marušič in spletni strani Živ? Živ! bomo, takoj ko bo to mogoče (odvisno od navodil znanstvenih revij, v katerih jih bomo objavili), predstavili rezultate dela, da se bodo lahko z njimi seznanili sodelujoči v raziskavi in širša javnost. Odgovori sodelujočih na vprašanja v vprašalnikih in drugi, s prostovoljci povezani podatki, bodo ostali anonimni, osebni podatki pa popolnoma anonimizirani (nedostopni).

Vrste meritev

V raziskavi bomo opravljali dve vrsti meritev (oziroma zbirali dve vrsti podatkov): samoocenjene podatke iz izpolnjenih vprašalnikov ter vzorce sline. Podrobneje jih lahko opredelimo:
Samoocenjeni podatki: zdravstveno stanje, uporaba hormonskih terapij ali zdravil, počutje in ocena psihičnega stanja. V tem sklopu bomo zajeli tudi sociodemografske dejavnike.
Vzorci sline: 7 vzorcev na prostovoljca na vsak del testa (skupno 14 vzorcev na vsakega prostovoljca). V vzorcih sline bomo izmerili vsebnosti prostega kortizola, ki je uporaben in uveljavljen pokazatelj stresa pri ljudeh v laboratorijskih poskusih

---

Namen in utemeljitev

Na področju raziskav restorativnih učinkov narave je v zadnjem času zaznati precejšen razvoj, še posebej glede restorativnih učinkov v grajenem bivanjskem okolju, saj v njem ljudje preživimo večino svojega časa. **Dosedanje raziskave** so pokazale neposredno povezavo med prisotnostjo lesa v grajenem bivanjskem okolju in zmanjševanjem stresa, vendar so na tem področju potrebne nadaljnje raziskave.
Pri raziskavah na tem področju proučujemo odnos med človekom in naravo in vpliv urbanega okolja, ki ni naravno, na zdravje in počutje ljudi. Raziskave so pokazale, da stik z naravo pospešuje zmanjševanje stresa. V eni od raziskav so izmerili hitrejše postoperativno okrevanje in manjšo potrebo po uporabi analgetikov pri pacientih, ki so imeli razgled na naravno okolje, kot pri tistih, ki jim to ni bilo omogočeno. Zaradi teh ugotovitev so raziskovalci želeli ugotoviti, če bi uvajanje elementov naravnega okolja v grajeno bivanjsko okolje imelo podobno pozitiven vpliv. V raziskavah so ugotavljali vpliv lesa na kakovost zraka v prostoru in na zdravje ljudi, ter proučevali kako preference posameznikov glede uporabe lesa v grajenem bivanjskem okolju te vplive modificirajo. Proučevali so tudi vpliv večje uporabe lesa v prostorih za postoperativno okrevanje na okrevanje pacientov ter s poskusi ugotavljali vpliv opremljenosti pisarniškega okolja z lesom (proučevali tudi vpliv barve in vzorcev lesa) na umirjanje stresa (umiritev stresa po stresnem dogodku).
Najnovejše raziskave so pokazale, da uporaba lesa pri notranji opremi tudi v bivanjskem okolju pozitivno učinkuje na zmanjševanje stresa pri stanovalcih. Vendar so v le peščici raziskav neposredno proučevali restorativne lastnosti lesa kot materiala v grajenem notranjem bivanjskem okolju. Da bi lahko tesneje vpeli uporabo lesa v restorativno okoljsko oblikovanje, potrebujemo precej več zanesljivih in preverljivih podatkov. A četudi je bilo kar nekaj od teh maloštevilnih raziskav neoptimalno načrtovanih, so vse dosedanje raziskave pokazale restorativen vpliv lesa na stanovalce. Zaradi omenjenih pomanjkljivosti še vedno ne poznamo vseh vplivov, ki jih ima uporaba lesa na zmanjševanje stresa, ostajajo pa tudi vrzeli v znanju o specifikah znanih vplivov rabe lesa v notranjem okolju ter o vplivih izbire tipov, količine (deleža) in lastnosti (npr. barve, vzorcev, masivnega lesa, kompozitov, itd.) lesa, ki naj bi povzročili restorativne učinke. Vse naštete raziskave nakazujejo pozitiven odnos med ljudmi in naravo, še posebej lesom, vidnim v opremi notranjega zidanega bivanjskega okolja. Ta odnos šele pričenjamo razumeti, zato potrebujemo nadaljnje raziskave na tem področju, ki bodo pokazale in prepričljivo dokazale njegove temeljne principe.
Meritve telesnega odziva na stres z opazovanjem delovanja hipotalamusno-hipofizno-adrenalne osi (HHA-os) endokrinskega sistema je učinkovit način proučevanja vpliva lesa v grajenem bivalnem okolju na človeka. Pri dosedanjih raziskavah vpliva lesa v notranjem okolju so spremljali odziv avtonomnega živčevja na stres, v novejšem času pa pri poskusih v

laboratorijskem okolju vse bolj uporabljamo HHA-os kot indikator odziva na stres in njegovo umirjanje. Vendar pa te metode še nihče ni uporabil za preučevanje vpliva lesa v grajenem bivalnem okolju na stres (po podatkih v dostopni literaturi).

Uporabljeni literaturni viri:

Derr V, Kellert SR (2013) Making children's environments "R.E.D.": Restorative environmental design and its relationship to sustainable design. In: Pavlides E, Wells J (eds): Proceedings of the 44th annual conference of the environmental design research association. Providence, Rhode Island, 29 May-1 June 2013

Dickerson SS and Kemeny ME (2004) Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. Psychol Bull, 130(3).

Dressendorfer RA et al. (1992) Synthesis of a cortisol-biotin conjugate and evaluation as a tracer in an immunoassay for salivary cortisol measurement. J Steroid Biochem, 43(7).

Gaab J, Blättler N, Menzi T, Pabst B, Stoyer S, & Ehlert U (2003) Randomized controlled evaluation of the effects of cognitive-behaviour stress management on cortisol responses to acute stress in healthy subjects. Psychoneuroendocrino, 28(6).

Hartig T (2004) Toward Understanding the Restorative Environment as a Health Resource. In Open Space: People Space. Engaging with the Environment. Edinburgh, 2004. OPENspace Research Centre. http://www.openspace.eca.ac.uk/conference/proceedings/PDF/Hartig.pdf (accessesd 24 Nov. 2013).

Hartig T, Korpela K, GW E, Gärling T (1997) A measure of Restorative Quality in Environments. Scand Hous Plan Res, 14.

Hellhammer DH, Wüst S , Kudielka BM (2009) Salivary cortisol as a biomarker in stress research. Psychoneuroendocrino, 34(2).

Kaplan S (1995) The restorative benefits of nature: toward an integrative framework. J Environ Psychol, 15(3).

Kaplan R and Kaplan S (1989) The experience of nature: A psychological perspective. Cambridge: Cambridge University Press.

Kirschbaum C, Kudielka, B, Gaab, J, Schommer, N, & Hellhammer, D (1999) Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamus-pituitary-adrenal axis. Psychosom Med, 61(2).

Kirschbaum C, Wust S , Strasburger CJ (1992) 'Normal' cigarette smoking increases free cortisol in habitual smokers. Journal of Life Science, 50(6).

Nyrud A and Bringlimark T (2010) Is interior wood use psychologically beneficial? A review of psychological responses toward wood. Wood Fiber Sci, 42(2).

Park, B, Tsunetsugu, Y, Kasetani, T, Hirano, H, Kagawa, T, Sato, M, Miyazaki, Y (2007) Physiological effects of Shinrin-yoku (taking in the atmosphere of the forest) -- using salivary cortisol and cerebral activity indicators. J Physiol Anthropol, 26(2).

Sakuragawa S, Miyazaki Y, Kaneko T, Makita T (2005) Influence of wood wall panels on physiological and psychological responses. J Wood Sci, 51(2).

Tsunetsugu Y, Miyazaki Y, Sato H (2002) The visual effects of wooden interiors in actual-size living rooms on the autonomic nervous activities. J Physiol Anthropol, 21(6).

Tsunetsugu Y, Miyazaki Y, Sato H (2007) Physiological effects in humans induced by the visual stimulation of room interios with different wood quantities. J Wood Sci, 53.

Tyrväinen, L. Ojala, A. Korpela, K. Lanki, T. Tsunetsugu, Y, & Kagawa, T (2014) The influence of urgan green environments on stress relief measures: a field experiment. J Environ Psychol, 38, 1-9.

Ulrich R (1984) View through a Window May Influence Recovery from Surgery. Science, 224(4647).

Ulrich R (1991) Effects of interior design on wellness: theory and recent scientific research. J Health Care Inter Des, 3(1).

Ulrich R, Simons, R, Losito, B, Fiorito, E, Miles, M, & Zelson, M (1991) Stress recovery during exposure to natural and urban environments. J Environ Psychol, 11.

Namen predlagane raziskave je torej proučiti vplive lesa, uporabljenega kot material za opremo notranjih prostorov (kot pohištvo, talne in stenske obloge, okras) na stres. Spoznati želimo ključne lastnosti lesa, ki prispevajo k pozitivnem vplivu na stres, pri uporabi lesa v notranjih prostorih. Želimo, da bi oblikovalci ta spoznanja lahko uporabili za zmanjšanje stresa na delovnih mestih, v šolah in po domovih in s tem povečali produktivnost ter izboljšali učenje in splošno počutje.

Izoblikovali smo naslednje **hipoteze**:

1) Najvišja raven stresa pri prostovoljcih bo v z lesom opremljenih prostorih nižja kot v kontrolnem prostoru, ki z lesom ne bo opremljen.

2) Umirjanje stresa pri prostovoljcih bo v z lesom opremljenih prostorih hitrejše v primerjavi s kontrolnim prostorom.
3) Najvišja raven stresa pri prostovoljcih bo v različno opremljenih prostorih različna.
4) Umirjanje stresa pri prostovoljcih bo v različno opremljenih prostorih različno.

Načrt raziskave in metode dela

Temeljna metoda, ki jo bomo uporabili pri izvedbi glavnega poskusa v tej raziskavi, je spremljanje ravni in umirjanja stresa pri prostovoljcih z meritvami prostega kortizola v slini (indikator psihofiziološkega stresa), v prostorih, opremljenih z različno količino različnih tipov lesa. Poskus bo takoimenovani 3^2 faktorski poskus, z naslednjimi dejavniki in ravnmi (Preglednica 1):

Preglednica 1: Dejavniki in njihove ravni v poskusu

dejavniki	**ravni**	
količina lesa	35%	65%
vzorec lesa	nepoudarjen	izrazit
barva lesa	svetla	temna

S kombiniranjem teh treh dejavnikov in dveh njihovih ravni bomo za raziskavo na različne načine opremili osem pisarnam podobnih testnih prostorov. Pri opremljanju dodatnega, kontrolnega prostora ne bomo uporabili lesa. Prostovoljce bomo testirali tako v kontrolnem kot v enem od opremljenih prostorov (izbira, v kateri različno opremljen prostor bo napoten posamezni prostovoljec, bo naključna), ter rezultate izrazili v primerjavi z odzivi v kontrolnem prostoru (poskus s primerjalno kontrolno skupino).

V raziskavo bomo zajeli 240 prostovoljcev, vsakega testirali v kontrolnem prostoru ter v enem izmed osmih prostorov, različno opremljenih z lesom (v vsakem od teh osmih prostorov po 30 prostovoljcev)

Anonimnost in varovanje osebnih podatkov

Zaradi zagotavljanja anonimnosti in varovanja osebnih podatko prostovoljcev rezultati testiranj in informacije o zdravstvenem stanju ne bodo nikakor povezani s katerim koli podatkom, ki bi omogočal identifikacijo. V prvi podatkovni zbirki bomo zbirali naslednje podatke: identifikacijsko številko prostovoljca, demografske podatke (spol, starost, zaposlitveni status, itd.), podatke o uporabi hormonskih terapij ali zdravil (npr. kontracepcijska sredstva, kortikoidni steroidi, ipd.), datum in čas poskusa, identifikacijsko številko vzorca sline, identifikacijsko oznako testnega prostora in identifikacijske oznake vprašalnikov. V drugi, ločeni podatkovni zbirki pa bomo hranili imena in kontaktne podatke prostovoljcev ter njihove Izjave o zavestni in svobodni privolitvi sodelujočih zdravih oseb.

Naključnost dodelitve/prisoje

Pred začetkom poskusov bomo ustvarili identifikacijsko številko prostovoljca in ji naključno prisodili oznaki »Vrstni red poskusov« in »Tip z lesom opremljenega prostora«. Postopek prisoje:

1. Ustvarili bomo 240 enoznačnih identifikacijskih številk
2. Izmed njih bomo naključno izbrali 120 identifikacijskih številk ter jim določili

oznako vrstnega reda poskusov »kontrolni prostor, z lesom opremljen prostor«. Preostalim 120 identifikacijskim številkam bomo določili oznako vrstnega reda poskusov »z lesom opremljen prostor, kontrolni prostor«.

3. Izmed v koraku 2. nadgrajenih identifikacijskih številk jih bomo naključno izbrali 30 in jim določili tip z lesom opremljenega prostora (naključno izbrana cifra med 1 in 8). Korak 3. bomo ponavljali, dokler ne bomo izčrpali vseh cifer oznake tipa opremljenega prostora in vseh identifikacijskih številk prostovoljcev.
4. Tako dobljene končne identifikacijske številke bomo naključno razvrstili v seznam. Ko bo prostovoljec podpisal Izjavo o zavestni in svobodni privolitvi sodelujočih zdravih oseb, mu bomo dodelili prvo prosto identifikacijsko številko s seznama. Pod to identifikacijsko številko bomo shranjevali podatke o testih in s testi povezane podatke, nikakor pa ne kakršnih koli podatkov, s katerimi bi bilo mogoče indetificirati prostovoljca.

Potek izvedbe testov

Spodaj opisani postopek bomo pri vsakem prostovoljcu ponovili dvakrat, in sicer v kontrolnem prostoru ter v enem od prostorov, ki bodo na različne načine opremljeni z lesom. Prvi poskus bomo izvedli, ko bo prostovoljec podpisal Izjavo o zavestni in svobodni privolitvi sodelujočih zdravih oseb, drugega pa na drug dan, za katerega se bomo dogovorili pred ali takoj po izvedbi prvega poskusa.

1. Prostovoljci bodo izpolnili kratek vprašalnik o oceni psihičnega počutja, na katerem bodo svoje počutje ocenili po v naprej pripravljeni vrednostni lestvici.
2. Prostovoljcem bomo s standardnim komercialno dostopnim vzorčevalnim pripomočkom odvzeli prvi vzorec sline (VS1).
3. Prostovoljci bodo vstopili v prostor in se v njem deset minut aklimatizirali.
4. Po preteku aklimatizacije jim bomo odvzeli drugi vzorec sline (VS2).
5. Po tem odvzemu jih bomo izpostavili stresorju:
    a. Stresor bo pet- do desetminutni prikaz slik obrazov, ki izražajo jezo, in nelagodje vzbujajočih/neprijetnih podob iz novic (npr. prometne nesreče, prikazi nasilja, itd.).
6. Po koncu stresorja bomo prostovoljcem znova odvzeli vzorec sline (VS3).
7. Po po-stresorskem vzorčenju (VS3) bomo vzorčenje ponavljali v naprej določenih intervalih 15 (VS4), 30 (VS5), 45 (VS6) in 60 minut (VS7) po prenehanju stresorja.
8. Po zadnjem odvzemu vzorca sline bodo prostovoljci izpolnili kratek vprašalnik, v katerem bodo ponovno, po enaki vrednostni lestvici kot v prejšnjem, ocenili svoje počutje ter dodali še podrobnejšo oceno svojega počutja med trajanjem poskusa

Vzorce sline bomo označili z identifikacijsko številko prostovoljca in serijsko številko (npr. 001234-T1, 001234-T2 – označbi, ki označujeta, da sta to prvi in drugi vzorec sline (VS1 in VS2), ki smo ju odvzeli prostovoljcu z identifikacijsko številko 001234 pri poskusu v z lesom opremljenem prostoru (T)). Odvzete vzorce sline bomo shranili po specifikacijah dobavitelja pripomočka za vzorčenje (pri približno -4°C) do odpreme na analizo v akreditiranem laboratoriju. Laboratoriju bomo dostavili vzorce sline, označene le s črtno kodo in pripadajočo identifikacijsko številko. Nobeden od teh podatkov ne bo omogočal identifikacije prostovoljcev.

Analiza podatkov

Z ustreznimi statističnimi metodami bomo proučili podatke o prostem kortizolu v slini in samoocenjene kvalitativne in kvantitativne podatke. V raziskavi bomo, v skladu z načrtom eksperimenta, primerjali ustrezno pripadajoče kontrolne meritve in meritve v z lesom opremljenem prostoru (primerjalne skupine), kar bomo morali upoštevati pri izbiri statističnih metod in obdelavi podatkov.

Razširjanje znanja

Pri vseh aktivnostih razširjanja znanja bomo ščitili osebne podatke prostovoljcev. Podatke bomo anonimizirali, rezultate pa objavljali in o njih diskutirali le v zbirni obliki.

OCENA ETIČNIH VIDIKOV RAZISKAVE

V raziskave bomo vključili le osebe, ki se bodo za to prostovoljno odločile po tem, ko jim bomo predhodno opisali osnovni namen raziskave, merilne postopke, koristi in tveganja. Pogoj za vključitev posameznika v raziskavo bo predhodno podpisana izjava o njegovi prostovoljni odločitvi.
Vsi merilni postopki, ki jih bomo uporabili v okviru našega projekta, so bili na človeku že uporabljeni in so dokazano varni.
S predlaganim projektom želimo proučiti vplive lesa, uporabljenega kot material za opremo notranjih prostorov (kot pohištvo, talne in stenske obloge, okras), na stres. Spoznati želimo ključne lastnosti lesa, ki prispevajo k pozitivnem vplivu na stres, da bi lahko vsi deležniki pri oblikovanju notranjih bivanjskih okolij ta spoznanja uporabili za zmanjšanje stresa v teh okoljih in s tem omogočili boljše zdravje in kvaliteto življenja.

5. Osebe, ki bodo povabljene v raziskavo

- V raziskavo bomo vključili le naključno izbrane osebe, ki se bodo za to prostovoljno odločile, ko jim bomo predhodno podrobno opisali osnovni namen raziskave (vpliv različne opremljenosti prostora na stres, ne da bi razkrili hipoteze o vplivu lesa na stres), merilne postopke, koristi in tveganja.
- Udeleženci raziskave ne bodo prejeli denarnega nadomestila, z rezultati raziskave pa se bodo lahko seznanili na spletni strani Inštituta Andrej Marušič.

Spodaj podpisana dr. Andreja Kutnar, univ. dipl. inž. les., vodja raziskave z naslovom »Les in stres v grajenem notranjem okolju« izjavljam, da vabila potencialnih subjektov za sodelovanje v raziskavi ne bo spremljal pritisk in/ali neprimerno napeljevanje.

doc. dr. Andreja Kutnar, univ. dipl. inž. les. ____ Andreja Kutnar

6. Skrb za varnost in koristi oseb v raziskavi

Vsi merilni postopki, ki jih bomo uporabili v okviru našega projekta, so bili na človeku že uporabljeni in so dokazano varni.
Po kliničnem intervjuju s psihologinjo bomo že pred testiranjem prostovoljcev izključili tiste, katerih zdravstvena ali psihološka stanja (npr. s stresom povezana stanja) bi lahko vplivala na izid raziskave, ali pa bi izpostavitev dodatnemu stresu lahko pomenila nepotrebno povečanje tveganja za poslabšanje njihovega zdravstvenega stanja (izključitveni kriterij bo prisotnost simptomov depresije, anksioznosti in samomorilnega vedenja). Raziskovalni protokol je sestavljen tako, da minimalizira vsakršno potencialno tveganje za udeležence med zbiranjem podatkov in testiranji. Da se bomo izognili potencialni škodi (psihološke bolečine, čustvene krize), ki bi jih lahko povzročila izpostavitev v testih načrtovanemu stresorju, bomo prostovoljcem (tudi tistim, ki bi jih po intervjuju s psihologinjo izločili) zagotovili

informacije o lokalni javno zdravstveni mreži in kriznih centrih. Te informacije bodo na voljo med in po končanem projektu.
Za primere neugodnih dogodkov se bomo zavarovali z izobraževanjem vseh vključenih raziskovalcev in sodelavcev na projektu za dobro prepoznavo rizičnih oseb.

7. Primerjalna skupina subjektov

Predlagana raziskava je tipičen primer »Within Subject Design«, pri kateri je vsak prostovoljec kontrola samemu sebi. Vsak prostovoljec bo sodeloval tako pri poskusu v kontrolnem kot v enem od naključno izbranih prostorov, na različne načine opremljenih z lesom. Vrstni red teh dveh testov bo za vsakega prostovoljca naključen, s tem pa želimo zmanjšati vpliv možne desenzitacije na stresor in/ali privajenosti na protokol poskusa. Iskani podatek bo razlika v rezultatih merjenja stopnje stresa v kontrolnem in v z lesom opremljenem prostoru. Pri prostovoljcu i bomo na primer izmerili najvišjo raven stresa v kontrolnem prostoru X_i ter najvišjo raven stresa v z lesom opremljenem prostoru Y_i; iskani podatek je potem Z, ki je razlika med obema najvišjima ravnema izmerjenega stresa pri prostovoljcu i $Z_i = X_i - Y_i$

8. Varovanje zaupnosti osebnih podatkov

V vseh fazah projekta bomo s kodiranjem in drugimi načini skrbeli za varovanje osebnih podatkov skladno z veljavno zakonodajo na tem področju. Ob koncu vsake študije bomo preiskovancem posredovali rezultate (anonimizirano, v zbirni obliki) in njihovo uporabnost na spletni strani Inštituta Andrej Marušič.

9. Dostopnost rezultatov raziskave udeležencem

Kot omenjeno v Točkah 5 in 8 bodo udeleženci raziskave ob koncu vsake študije rezultate (anonimizirano, v zbirni obliki) in njihovo uporabnost pregledali na spletni strani Inštituta Andrej Marušič.

10. Naročnik in plačnik raziskave

Projekt/raziskava je financirana s strani Univerze na Primorskem

11. Predhodna ocenjevanja etičnih komisij

Predlagana raziskava predhodno ni bila obravnavana na drugih etičnih komisijah.

12. Izjava odgovornega raziskovalca

Podpisana doc. dr. Andreja Kutnar, univ. dipl. inž. les., vodja raziskave z naslovom »Les in stres v grajenem notranjem okolju«, izjavljam, da bom v raziskavi spoštovala načela Kodeksa etike zdravstvenih delavcev Slovenije, Oviedske konvencije in Tokijske deklaracije.

doc. dr. Andreja Kutnar, , univ. dipl. inž. les. Andreja Kutnar

13. Obrazec izjave o zavestni in svobodni privolitvi sodelujočih zdravih oseb

*1. Ime in priimek udeleženca raziskave*______________________________________
starost_________ .

2. Naslov raziskovalne ustanove: Univerza na Primorskem, Inštitut Andrej Marušič
3. Naslov raziskave: »Les in stres v grajenem notranjem okolju«,

4. Izjava udeleženca raziskave:
Podpisani, kot udeleženec raziskave, sem razumel metodo raziskave. Seznanjen sem bil z neprijetnostmi in koristmi meritev. Moje sodelovanje v raziskavi je popolnoma prostovoljno in ga lahko odklonim ali izstopim iz raziskave. Obvestili so me, da bodo rezultati te raziskave služili napredku medicinskega znanja. Vem, da je metodologijo te raziskave predlagala in odobrila Republiška strokovna komisija za medicinska etična vprašanja. Dobrobit, tveganja in nevšečnosti mi je razumljivo razložila dr. Andreja Kutnar, ki je odgovorna za mojo varnost v teku raziskave. Zato prostovoljno in svobodno pristajam na sodelovanje v tej

raziskavi.

Datum: ____________ Podpis udeleženca raziskave:_______________________

Izjava preiskovalca:
Podpisani sem razumljivo razložil udeležencu raziskave dobrobit, tveganje in nevšečnosti sodelovanja v raziskavi.

Datum:_____________ Podpis preiskovalca: _____________________

14. Informacija za vzpostavitev stika sodelujočih z odgovornim zdravnikom

Slovenski center za raziskovanje samomora
Kettejeva 1, II/8, 6000 Koper
Pisarna: +386 5 611 76 56
Mobilna št.: +386 40 490 580

In vse od tu: http://zivziv.si/sos/

15. Nevarnost teratogenih učinkov

Pri predlagani raziskavi ni nevarnosti teratogenih učinkov.

16. Datum oddaje vloge in podpis predlagatelja

Koper, 06.11. 2014 doc. dr. Andreja Kutnar, univ. dipl. inž. les.

Andreja Kutnar

Psychiatric Research Unit
WHO Collaborating Centr in Mental Health

WHO (pet) kazalec blaginje (različica 1998)

Prosimo, da za vsako od petih trditev označite, katera je najbližja vašemu počutju v zadnjih dveh tednih. Višje številke pomenijo boljše počutje.

Primer: če ste se zadnja dva tedna več kot polovico vsega časa počutili vedri in dobre volje, označite okvirček, ki ima številko 3 v zgornjem desnem kotu.

	V zadnjih dveh tednih sem se/je bil	ves čas	večino časa	več kot polovico časa	manj kot polovico časa	nekaj časa	nikoli
1	**počutil(a) vedro in dobre volje**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
2	**počutil(a) pomirjeno in sproščeno**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
3	**počutil(a) živahno in poln(a) energije**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
4	**zbudil(a) svež(a) in spočit(a)**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
5	**moj vsakdan zapolnjen s stvarmi, ki me zanimajo**	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0

Točkovanje:

Skupno število točk izračunate tako, da seštejete število točk vseh petih odgovorov. Skupno število točk se giblje med 0 in 25, 0 predstavlja najslabšo možno in 25 najboljšo možno kakovost življenja.

Skupno število točk pretvorite v odstotke od 0 do 100 tako, da število točk pomnožite s 4. 0 odstotkov predstavlja najslabšo možno, 100 odstotkov pa najboljšo možno kakovost življenja.

Obrazložitev:

Če je skupno število točk manjše od 13 ali če je bolnik na katerokoli od petih trditev odgovoril z 0 ali 1, je priporočljivo testiranje za depresijo z diagnostičnim instrumentom za depresijo, kot je Major Depression (ICD-10) Inventory. Skupno število točk, nižje od 13, pomeni nizko blaginjo posameznika in nakazuje potrebo po testiranju za depresijo po ICD-10.

Spremljanje sprememb:

Za spremljanje morebitnih sprememb v blaginji uporabljamo odstotne točke. 10% razlika označuje značilno spremembo (John Ware, 1996).

KOMISIJA REPUBLIKE SLOVENIJE ZA MEDICINSKO ETIKO

Doc. dr. Andreja Kutnar, univ. dipl. inž. lesarstva
Inštitut Andrej Marušič
Univerza na Primorskem
Muzejski trg 2
6000 Koper

Štev.: 78/12/14
Datum: 22. 12. 2014

Spoštovana gospa doc. dr. Kutnar,

z datumom 6. 11. 2014 ste Komisiji za medicinsko etiko (KME) poslali v oceno predlog raziskave z naslovom:

"Les in stres v grajenem notranjem okolju." "Wood and human stress in the built indoor environment." Doktorska disertacija Michaela Davida Burnarda.

KME je na seji 16. decembra 2014 ocenila, da je raziskava etično sprejemljiva, in vam s tem izdaja svoje soglasje za njeno izvedbo.

Lep pozdrav,

dr. Božidar Voljč, dr. med.,
predsednik Komisije RS za medicinsko etiko

Naslov:
Komisija RS za medicinsko etiko, Inštitut za klinično nevrofiziologijo, Zaloška 7, 1525 Ljubljana
Telefon: 01/522-1509, telefaks: 01/522-1533, naslov za elektronsko pošto: Tone.Zakelj@kclj.si
http://www.kme-nmec.si/

Wood and human stress in the built indoor environment: Data processing and analysis

Michael David Burnard, University of Primorska, Koper, Slovenia

05 December 2017

Contents

Introduction

This document contains the code and procedures for the analysis of salivary free cortisol levels used as an indicator of stress in "Wood and human stress in the built indoor environment", the PhD dissertation by Michael David Burnard at the University of Primorska, Faculty of Management, Koper Slovenia. Mentor: Assoc. prof. Andreja Kutnar, PhD.

The analysis includes extracting cortisol levels and other information from the microtitre plates saliva samples were processed on and various statistical, summary, and visual analyses used to understand the data and determine the results of the experiment.

The data are not included because individuals and their health data may be identifiable. Sanitized, psuedoanonymous data may be available upon request in qualified circumstances.

Setting the Environment

```
library(drc)
library(tidyverse)
library(stringr)
library(ggforce)
library(scales)
library(zoo)
```

Data

Prepare storage data frames

Here we:

1. Create a data frames to store our important info
   a. Results (readings, cortisol levels, participant id, test info)
   b. Information about the model and its fit
   c. Information about each processed tray (calibrators, controls, etc)
2. Create a list to store models. We want to come back to inspect them later.

```
results <- data.frame("Subject" = as.character(), "Test" = as.integer(),
                      "Interval" = as.numeric(), "Tray" = as.integer(),
                      "Reading.mu" = as.double(), "Cortisol.fitted.ng" = as.double(),
                      "Cortisol.fitted.nmol"=as.numeric())
control <- data.frame("Name" = as.character(), "Reading.mu" = as.double(),
                      "Tray" = as.integer(), "Cortisol.fitted.ng" = as.double(),
                      "Cortisol.fitted.nmol"=as.numeric())
model.info <- data.frame("Tray" = as.integer(), "b" = as.double(),
                         "c" = as.double(), "d" = as.double(),
                         "e" = as.double(), "Resid.var" = as.double())
tray.info <- data.frame("Tray" = as.integer(), "Reading.name" = as.character(),
                        "Reading.value_1" = as.double(),
                        "Reading.value_2" = as.double(), "Reading.mu" = as.double(),
                        "Reading.absDiff"=as.double(),
                        "Fit.value.ng" = as.double(), "Fit.value.nmol"=as.numeric(),
                        "ExpectedRaw.value" = as.double(),
                        "ExpectedFit.value" = as.numeric())
models.list <- vector("list", 25)
```

Read, parse, and calculate cortisol concentrations

Data files from the microtitre plate reader were stored in a single folder that was read, processed, and stored as follows. Files associating the readings with subject identifiers were also read and matched to the data for processing.

```
for(i in 1:25)
{
  #read data
  readings.path <- paste("data/cortisol/Readings/CortisolReadings_tray",
                         as.character(i), ".csv", sep="")
  layout.path <-  paste("data/cortisol/Layouts/CortisolLayout_tray",
                         as.character(i), ".csv", sep="")

  readings.all <- read.csv(readings.path, stringsAsFactors=FALSE)
  layout.all <- read.csv(layout.path, stringsAsFactors=FALSE)

  #prep data
  readings.all <- gather(readings.all, "Col", "Reading", 2:13)
  readings.all$Col <- as.numeric(str_sub(readings.all$Col, 2))
  layout.all <- gather(layout.all, "Col", "Name", 2:13)
  readings.all$Name <- layout.all$Name

  #Split data into useful groups
  readings.subject <- readings.all %>% filter(str_length(Name) > 5)
  readings.calib <- readings.all %>% filter(str_detect(Name, "C{1}[0123456]") == TRUE)
  readings.control_a <- readings.all %>% filter(str_detect(Name, "C{1}[LHM]") == TRUE)
  readings.control_b <- readings.all %>% filter(str_detect(Name, "C{1}[o]") == TRUE)

  #two temporary storage frames
  readings.calib_t <- readings.calib[,3:4]
  readings.control_t <- bind_rows(readings.control_a[,3:4], readings.control_b[,3:4])

  #finalise data prep
  readings.subject <- readings.subject %>%
    separate(Name, c("Subject", "Test", "Interval", "Position"), convert=TRUE) %>%
    group_by(Subject, Test, Interval) %>% summarise(Reading.mu = mean(Reading)) %>%
    mutate(Tray = i)
  readings.calib <- readings.calib %>% separate(Name, c("Name", "Position")) %>%
    group_by(Name) %>% summarise(Reading.mu = mean(Reading)) %>% mutate(Tray = i)
  readings.control_a <- readings.control_a %>% separate(Name, c("Name", "Position")) %>%
     group_by(Name) %>% summarise(Reading.mu = mean(Reading)) %>% mutate(Tray = i)
  readings.control_b <- readings.control_b %>% ungroup() %>%
    mutate(Reading.mu = Reading, Tray = i)
  readings.control <- bind_rows(readings.control_a, readings.control_b[,c(4,5,6)])
  #the same except for summarise for the temp storage frames
  readings.calib_t <- readings.calib_t %>% separate(Name, c("Name", "Position"))
  readings.control_t <- readings.control_t %>% separate(Name, c("Name", "Position"))

  #add cortisol values for model fitting & storage
  readings.calib$Cortisol <- c(0.0, 0.5, 1, 5, 10, 20, 100)

  #fit a model and store it in our list of models to look at later.
  #there is a special case for tray 23 because of a robot error
  #the robot missed a row (probably a pipette wasn't well attached)
  if(i == 23) {
    readings.calib <- readings.calib %>% filter(Name != "C1")
    m <- drm(Cortisol~Reading.mu, data=readings.calib, fct=LL.4())
```

```
    models.list[[i]] <- m
    names(models.list)[[i]] <- paste("Tray", i, sep="_")
    tmp.row <- data_frame("Name"="C1", "Reading.mu"=NA, "Tray"=i, "Cortisol"=0.5)
    readings.calib <- bind_rows(readings.calib, tmp.row) %>% arrange(Cortisol)
  }
  else {
    m <- drm(Cortisol~Reading.mu, data=readings.calib, fct=LL.4())
    models.list[[i]] <- m
    names(models.list)[[i]] <- paste("Tray", i, sep="_")
  }

  #store model info in a data frame to compare
  temp.row <- data.frame("Tray" = i, "b" = coef(m)[[1]], "c" = coef(m)[[2]],
                         "d" = coef(m)[[3]], "e" = coef(m)[[4]],
                         "Resid.var" = summary(m)[[1]])
  model.info <- bind_rows(model.info, temp.row)

  #store calibration and control readings
  readings.calib_t <- spread(readings.calib_t, Position, Reading)
  temp.df <- as.data.frame(cbind(rep(i, 7),
                         readings.calib_t$Name,
                         readings.calib_t[2],
                         readings.calib_t[3],
                         (readings.calib_t[2] + readings.calib_t[3]) / 2,
                         abs(readings.calib_t[2] - readings.calib_t[3]),
                         rep(1,7),
                         c(2.643, 2.229, 2.056, 1.295, 0.789, 0.451, 0.131),
                         readings.calib$Cortisol))
  names(temp.df) <- c("Tray", "Reading.name", "Reading.value_1" ,
                      "Reading.value_2", "Reading.mu",
                      "Reading.absDiff", "Fit.value.ng",
                      "ExpectedRaw.value", "ExpectedFit.value")
  temp.df$Fit.value.ng <- fitted(m, temp.df[,c(4,1)])
  temp.df$Fit.value.nmol <- temp.df$Fit.value.ng * 2.76 # add nmol/L value

  #another correction for tray 23
  if(i == 23) { temp.df <- temp.df[-2,]}
  tray.info <- bind_rows(tray.info, temp.df)
  tray.info$ExpectedFit.value.nmol <- tray.info$ExpectedFit.value * 2.76

  #use the fitted model to back calculate
  readings.subject$Cortisol.fitted.ng <- fitted(m, readings.subject[,4])
  readings.subject$Cortisol.fitted.nmol <- readings.subject$Cortisol.fitted.ng * 2.76
  results <- bind_rows(results, readings.subject[,c(1,2,3,5,7,4,6)])

  #and for controls
  readings.control$Cortisol.fitted.ng <- fitted(m, readings.control[,2])
  readings.control$Cortisol.fitted.nmol <- readings.control$Cortisol.fitted.ng * 2.76
  control <- bind_rows(control, readings.control)

}
```

Now, merge Test Record data (video, room, test sequence, etc.) with results. We also make an pseudoanonymous identifier that isn't associable with the subject identities. Because of anonymisation, this isn't run here. Instead we read a file with the saved results.

```
#Read the file and select the columns of interest
tr <- read.csv("data/TestRecord.csv", stringsAsFactors=FALSE)
```

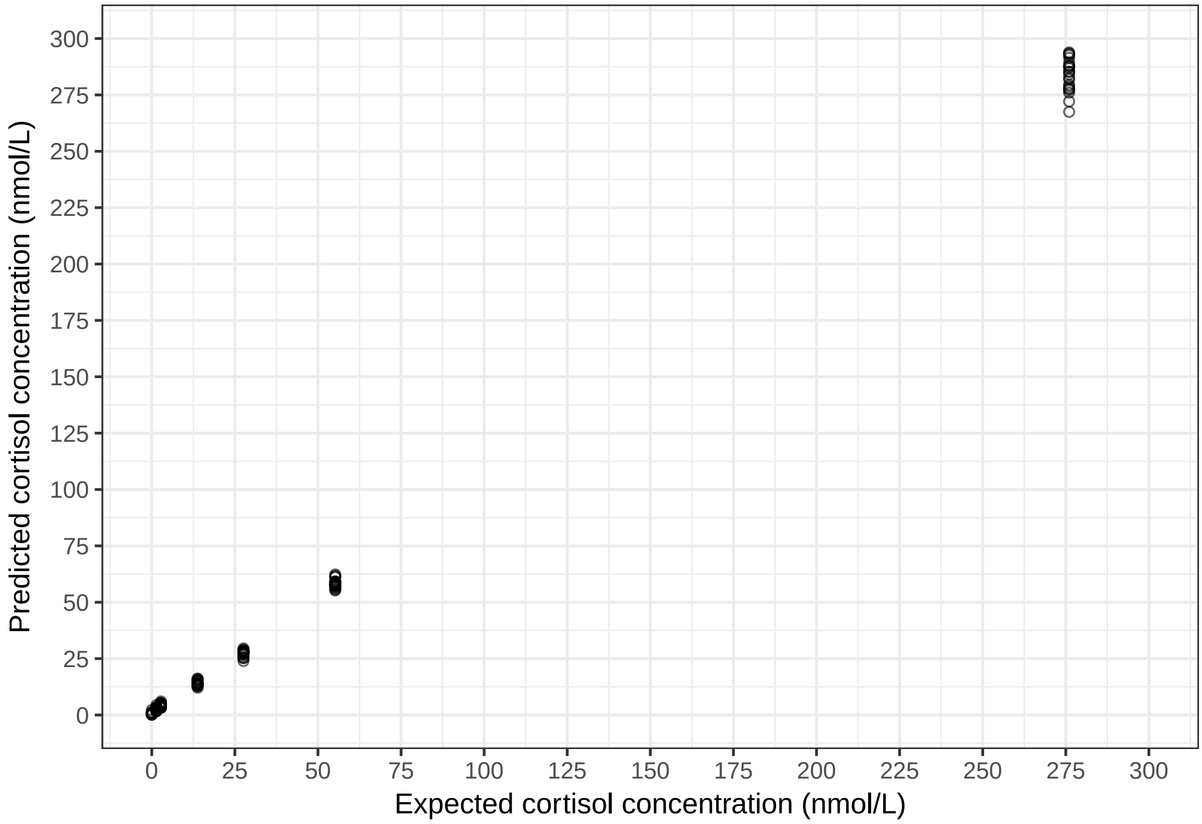
```
tr <- tr %>% select(Participant, TestType, Room, Video, SGL, WHO5_Total)
#rename for the merge
names(tr)[1] <- "Subject"
names(tr)[5] <- "Test"

#Merge them with the results
results <- left_join(results, tr, by=c("Subject", "Test"))

#Add a character string to further anonomise the results in output plots.
makeRandString <- function() {
  tmp = c(sample(LETTERS, 3, replace=TRUE),
    sample(0:9, 2, replace=TRUE))
  return(paste0(tmp, collapse=""))
}


results <- results %>% group_by(Subject) %>% mutate(Anon=makeRandString())
# verify unique for each subject
length(unique(results$Anon))
```

```
results <- read.csv("results_storage.csv", stringsAsFactors = FALSE, header = TRUE)
#to double check we have 14 total for each subject

verify <- data.frame(table(results$Subject, results$Tray))
verify <- spread(verify, Var2, Freq)
verify <- verify %>% mutate(RowSum = rowSums(verify[,2:26]))

#The pipette robot had a small malfuction (didn't seal a pipette tip) on one tray
#rendering the values from row unuseable.
results$Cortisol.fitted.ng <- ifelse(results$Tray == 23 & results$Interval == 2, NA,
                                     results$Cortisol.fitted.ng)
results$Cortisol.fitted.nmol <- ifelse(results$Tray == 23 & results$Interval == 2, NA,
                                       results$Cortisol.fitted.nmol)

#add time in minutes
results$Minutes <- ifelse(results$Interval == 1, 0,
                    ifelse(results$Interval == 2, 15,
                    ifelse(results$Interval == 3, 25,
                    ifelse(results$Interval == 4, 35,
                    ifelse(results$Interval == 5, 45,
                    ifelse(results$Interval == 6, 60, 75))))))

#3 subject-test combos were duplicated on tray 25 for verification
# XX-2, XX-1, XX-2. Need to remove these from the general results
#and keep them to check.
check <- results %>% filter ((Anon %in% c("XGD55","FQX13","KHO49") & Tray == 25))
results <- results %>% filter( !(Anon %in% c("XGD55","FQX13","KHO49") & Tray == 25) )
```

Plate to Plate comparisons and results

```
ggplot(data=tray.info,
       aes(x=ExpectedFit.value * 2.76, y=Fit.value.ng * 2.76)) + theme_bw() +
  geom_point(alpha=.6, shape=1) +
  scale_x_continuous(limits=c(0,300), breaks=seq(0,300,25)) +
  scale_y_continuous(limits=c(0,300), breaks=seq(0,300,25)) +
```

```
  labs(x="Expected cortisol concentration (nmol/L)",
       y="Predicted cortisol concentration (nmol/L)")
```




```
tray.fit <- tray.info %>% select(Tray, Fit.value.nmol, ExpectedFit.value.nmol) %>%
  group_by(Tray) %>%
  summarise(RMSE = sqrt(mean((Fit.value.nmol - ExpectedFit.value.nmol)^2)))

model.info$RMSE <- tray.fit$RMSE
#write.csv(file="Model_info.csv", model.info)
#write.csv(file="Calibrators.csv", tray.info %>% group_by(Reading.name)
#%>% summarise(mu = mean(Fit.value.nmol), med=median(Fit.value.nmol),
#sd=sd(Fit.value.nmol), coef.v=sd/mu, min=min(Fit.value.nmol),max=max(Fit.value.nmol)) )

#these are articially high, because of what we are measuring
#the results are near perfect because we are measuring curves fit to a known value
#to other curves fit to the same known value.
r2 <- 1 - (sum((tray.info$ExpectedFit.value.nmol - tray.info$Fit.value.nmol)^2) /
             sum((tray.info$Fit.value.nmol - mean(tray.info$Fit.value.nmol))^2))

rho <- cov(tray.info$Fit.value.nmol, tray.info$ExpectedFit.value.nmol) /
  (sd(tray.info$Fit.value.nmol) * sd(tray.info$ExpectedFit.value.nmol))

tray.info %>% group_by(Reading.name) %>% summarise(min=min(Reading.mu))
```

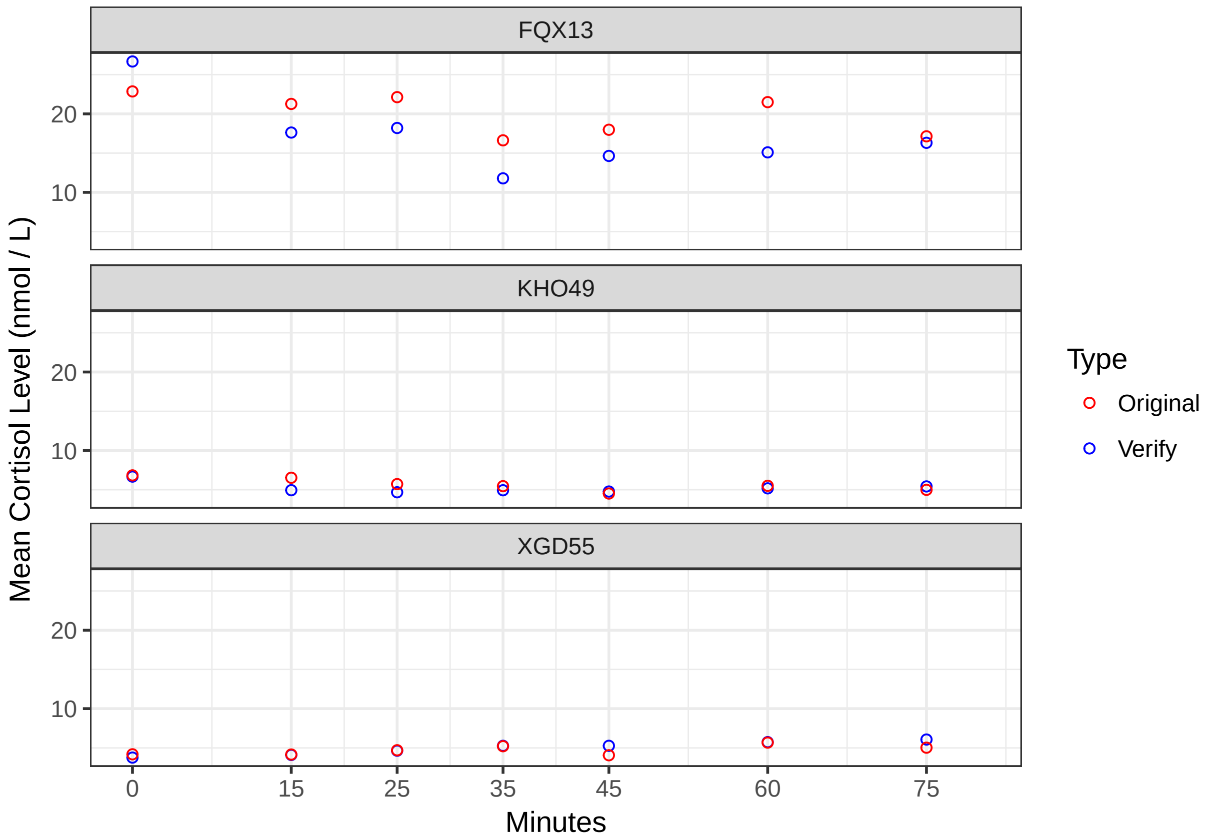
Reading.name	min
C0	1.7185
C1	1.4730
C2	1.2960
C3	0.8275
C4	0.5870
C5	0.3860

Reading.name	min
C6	0.1415

Duplicate testing

Three sample groups were tested in duplicate (on different trays) to guage tray-to-tray variation.

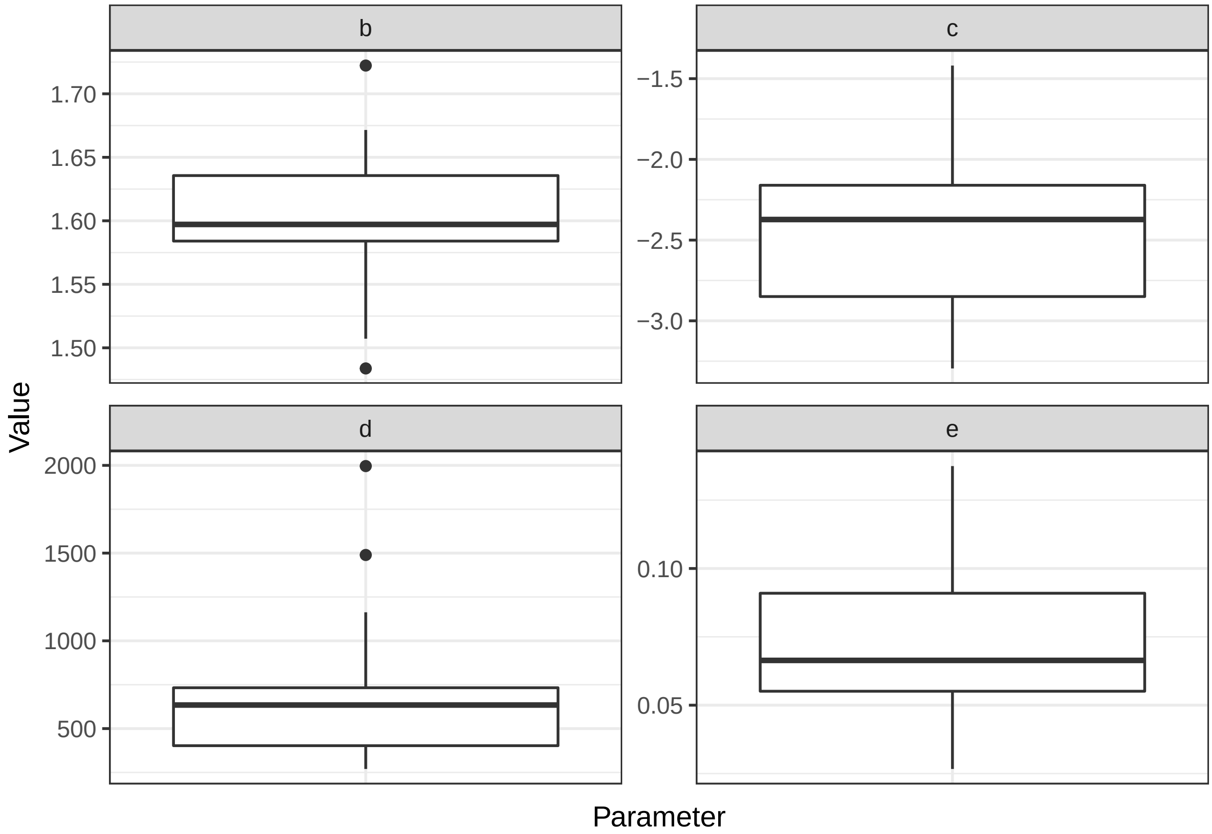
```
#plate to plate

#first, the duplicated trio

chck <- check %>% select(Subject, Anon, Test, Tray, Minutes, Reading.mu,
                         Cortisol.fitted.nmol)
r.chck <- results %>% select(Subject, Anon, Test, Tray, Minutes, Reading.mu,
                             Cortisol.fitted.nmol) %>%
  filter( (Anon == "XGD55" & Test == 1) |
          (Anon == "FQX13" & Test == 2) |
          (Anon == "KHO49" & Test == 2))
r.chck$Type <- "Original"
chck$Type <- "Verify"
chck <- bind_rows(chck, r.chck)

ggplot(data=chck, aes(x=Minutes, y=Cortisol.fitted.nmol, colour=Type)) + theme_bw() +
  geom_point(shape=1) +
  facet_wrap(~Anon, nrow=3) +
  scale_x_continuous(limits=c(0,80), breaks=c(0,15,25,35,45,60,75)) +
  scale_colour_manual(values=c("#FF0000", "#0000FF")) +
  labs(x="Minutes", y="Mean Cortisol Level (nmol / L)")
```



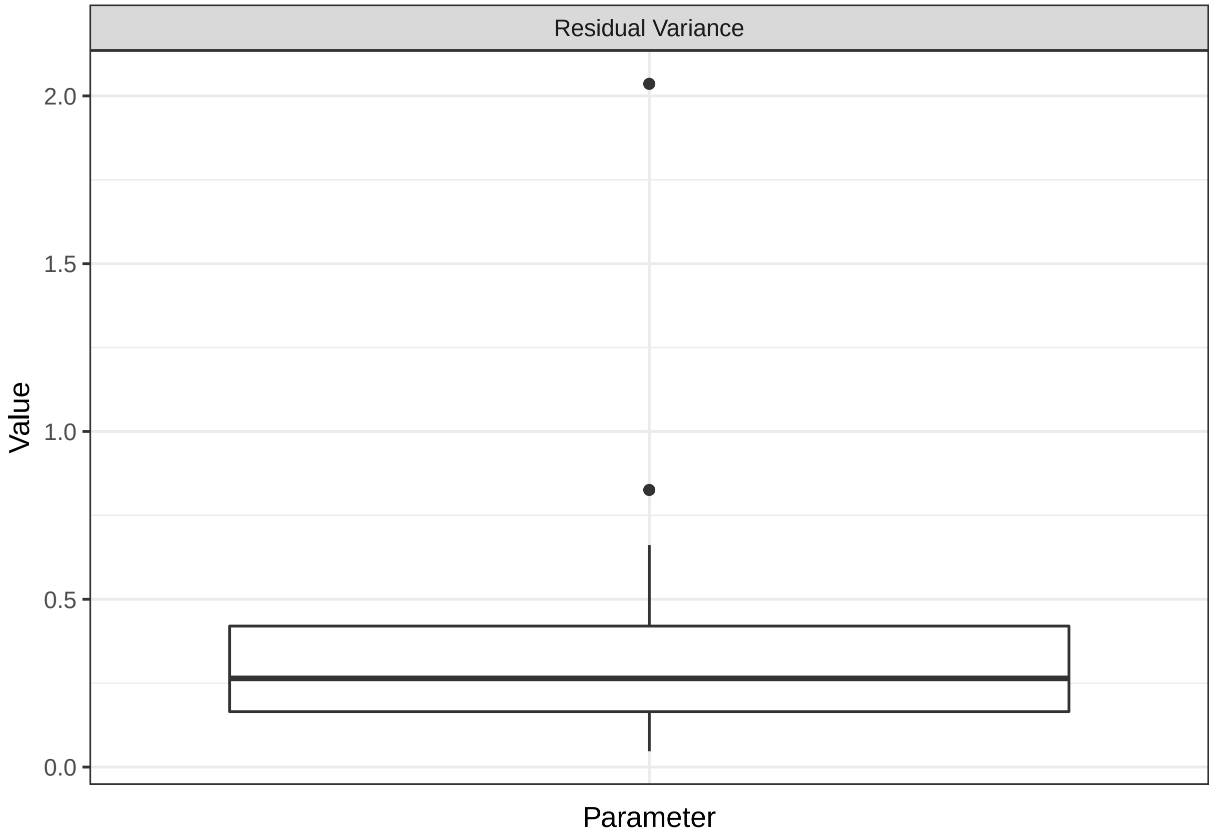
```
#now values
chck.o <- chck %>% filter(Type == "Original") %>%
  select(Subject, Cortisol.fitted.nmol)%>%  arrange(Subject)
chck.v <- chck %>% filter(Type == "Verify") %>%
  select(Subject, Cortisol.fitted.nmol) %>%  arrange(Subject)
names(chck.o)[2] <- "Original"
names(chck.v)[2] <- "Verify"

chck.o$Verify <- chck.v$Verify

chck.o$RawDiff <- abs(chck.o$Verify - chck.o$Original)
chck.o$PerDiff <- abs((chck.o$Verify - chck.o$Original) / chck.o$Verify)

chck.o <- chck.o %>% group_by(Subject) %>%
  summarise(raw.mu = mean(RawDiff), per.mu = mean(PerDiff))
```

Model and fit parameters

```
#consistency of fit parameters
mod.con <- gather(model.info, "Parameter", "Value", 2:6)
mod.con$Parameter <- ifelse(mod.con$Parameter == "Resid.var",
                            "Residual Variance", mod.con$Parameter)

ggplot(data=mod.con[which(mod.con$Parameter != "Residual Variance"),],
       aes(x=Parameter, y=Value)) + theme_bw() +
  geom_boxplot() +
  facet_wrap(~Parameter, scales="free") +
  theme(axis.text.x=element_blank(), axis.ticks.x=element_blank())
```



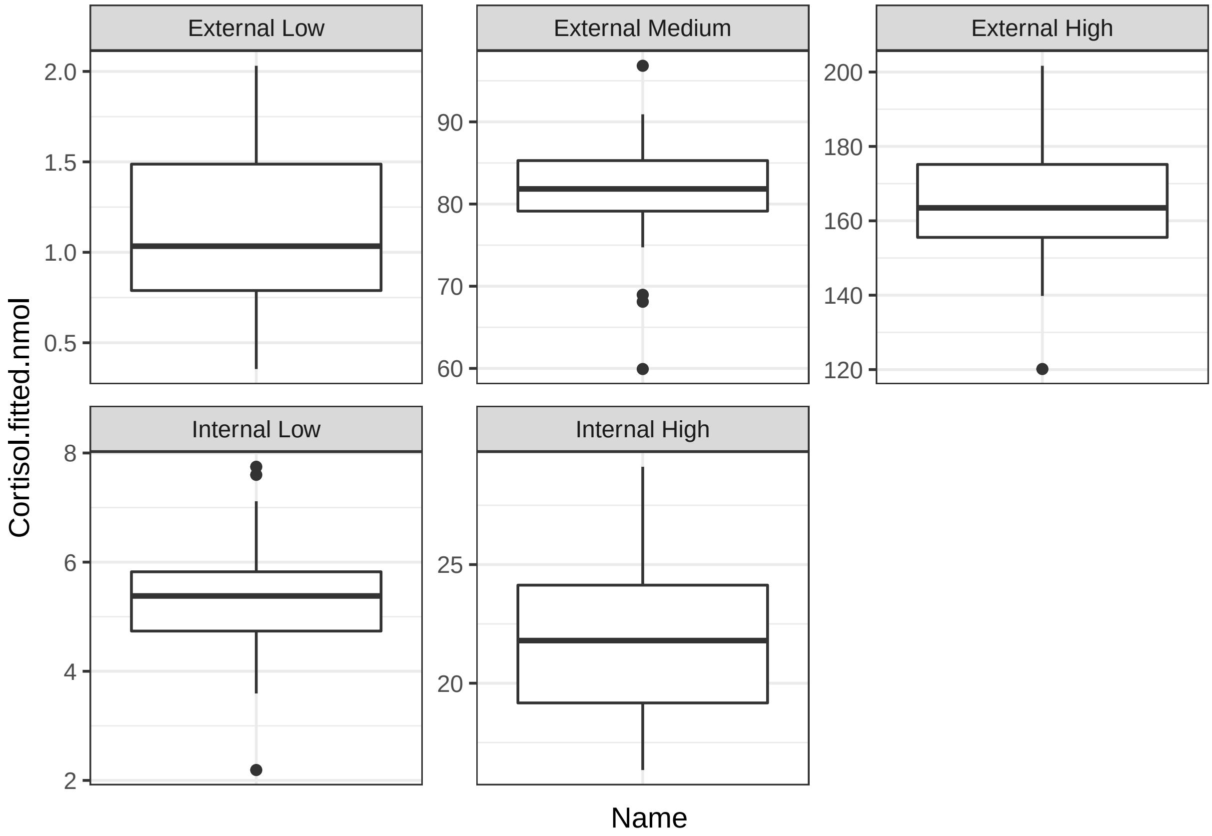
```r
ggplot(data=mod.con[which(mod.con$Parameter == "Residual Variance"),],
       aes(x=Parameter, y=Value)) + theme_bw() +
  geom_boxplot() +
  facet_wrap(~Parameter) +
  theme(axis.text.x=element_blank(), axis.ticks.x=element_blank())
```




```r
#plot(models.list$Tray_23)
```

Tray controls

```r
#Clear names for labels
control$Labels <- ifelse(control$Name == "CH", "External High",
                  ifelse(control$Name == "CL", "External Low",
                  ifelse(control$Name == "CM", "External Medium",
                  ifelse(control$Name == "Con-B", "Internal High",
                  ifelse(control$Name == "Con-A", "Internal Low", "Zed")))))
control$Labels <- as.factor(control$Labels)
control$Labels <- factor(control$Labels, levels=c("External Low", "External Medium",
                                                   "External High", "Internal Low",
                                                   "Internal High"))

ggplot(data=control %>% filter(Tray != 23), aes(x=Name, y=Cortisol.fitted.nmol)) +
  theme_bw() +
  geom_boxplot() +
  facet_wrap(~Labels, scales="free") +
  theme(axis.text.x=element_blank(), axis.ticks.x=element_blank())
```

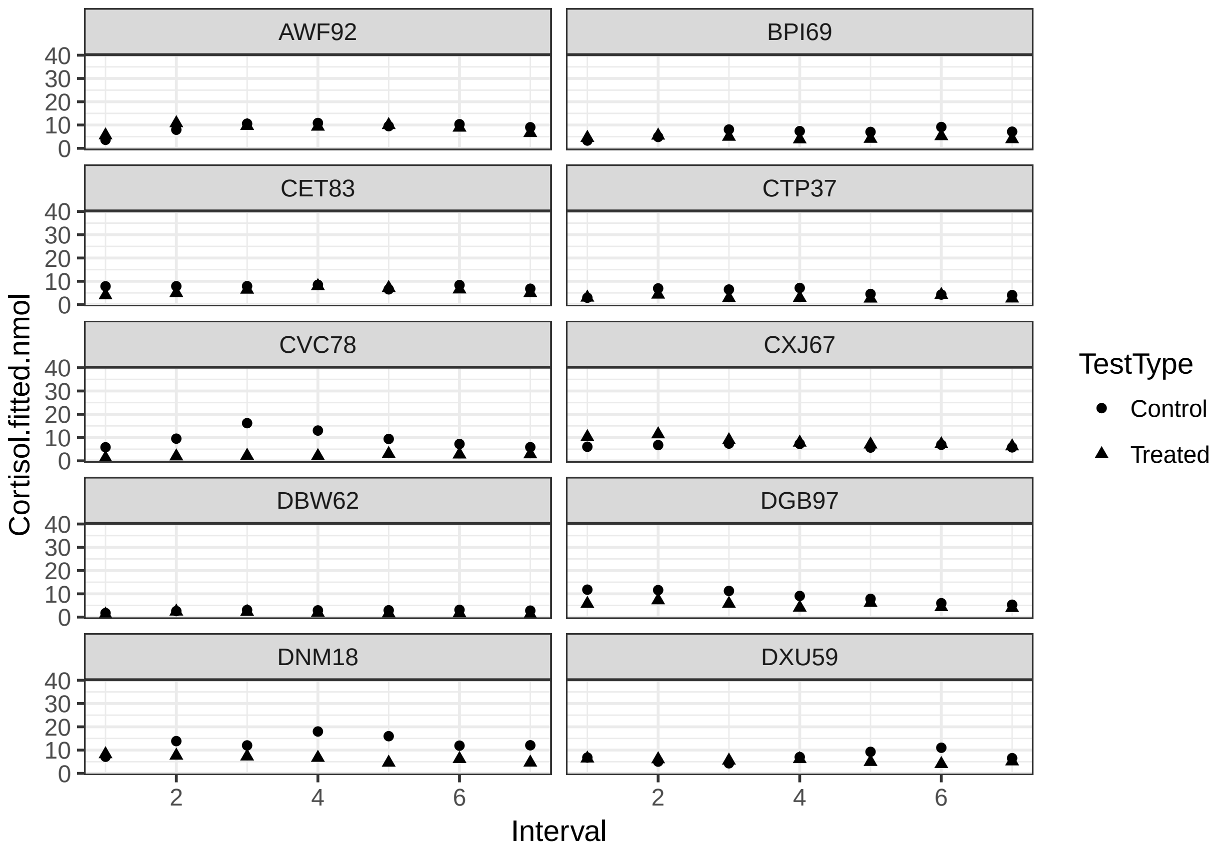


Results inspection for comparisons

Now we can graphically and statistically inspect the results.

```
#change page=X to see different pages.
ggplot(data=results, aes(x=Interval, y=Cortisol.fitted.nmol, shape=TestType)) +
  theme_bw() +
  geom_point() +
  facet_wrap_paginate(~Anon, ncol=2, nrow=5, page=1)
```

```
## Warning: Removed 5 rows containing missing values (geom_point).
```

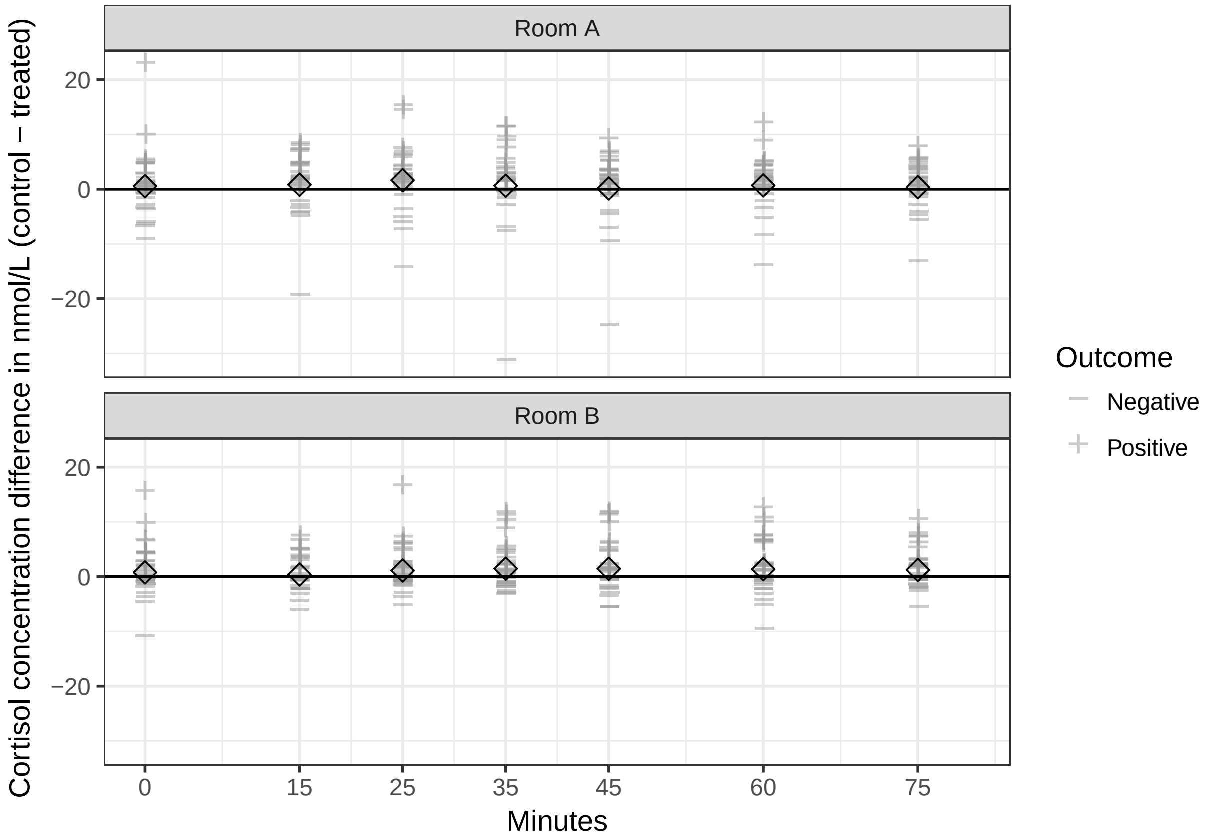



```
#generally all are fine except for DYG49. It's a very bizarre pattern for the
#treated test. Strange enough to warrant removal.
#The pattern doesn't follow expectations, and the values for tests are too
#different to provide much confidence. One situation or the other might be acceptable
#both are not.

r1 <- results %>% filter(Subject != "DYG49")

#first, check the responses to videos were not different


r1.vid <- r1 %>% group_by(Subject, Anon, Video) %>% filter(Interval %in% c(5,6,7)) %>%
  summarise(Test.mu=mean(Cortisol.fitted.nmol, na.rm=TRUE))
r1.vid <- r1.vid %>% group_by(Subject) %>% mutate(testDif=Test.mu - lag(Test.mu))
r1.vid$Outcome <- ifelse(is.na(r1.vid$testDif), "X",
                ifelse(r1.vid$testDif < 0, "Positive",
                 "Negative"))
r1.vid$Outcome <- ifelse(r1.vid$Outcome == "X", lead(r1.vid$Outcome), r1.vid$Outcome)
r1.vid <- r1.vid %>% select(Subject, Anon, Video, Test.mu) %>%
  ungroup() %>% spread(Video, Test.mu)

wilcox.test(r1.vid$A, r1.vid$B, paired=TRUE)
```

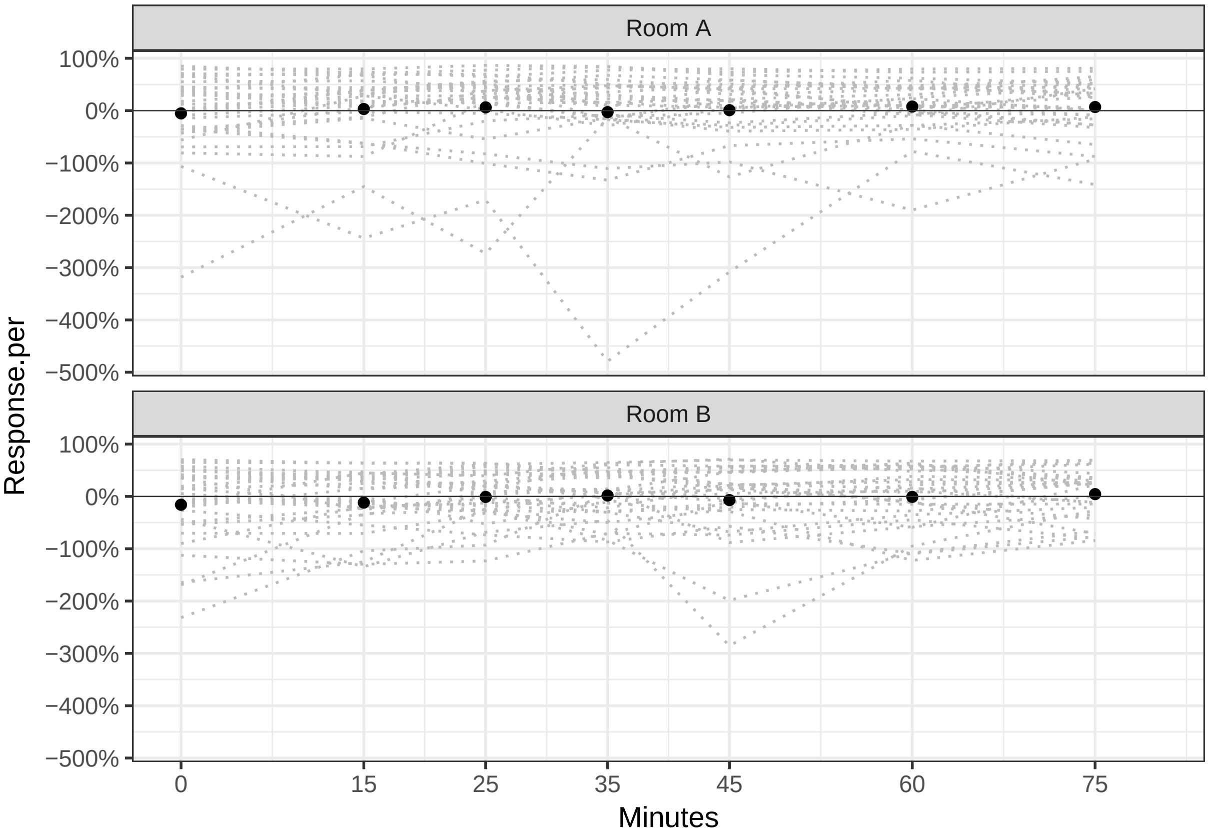
```
##
##  Wilcoxon signed rank test with continuity correction
##
## data:  r1.vid$A and r1.vid$B
## V = 881, p-value = 0.6457
## alternative hypothesis: true location shift is not equal to 0
```

```
r1.int <- r1 %>% select(Subject, Anon, Room, TestType, Interval,
                        Minutes, Cortisol.fitted.nmol) %>%
```

```
  spread("TestType", Cortisol.fitted.nmol) %>%
  mutate(Labels = ifelse(Room == "Oak", "Room A", "Room B"))

r1.int <- r1.int[complete.cases(r1.int),]

r1.int$Response <- r1.int$Control - r1.int$Treated
r1.int$Response.per <- r1.int$Response / r1.int$Control
r1.int$Outcome <- ifelse(r1.int$Response > 0, "Positive", "Negative")
r1.int.mu <- r1.int %>% group_by(Labels, Minutes) %>%
  summarise(mu.raw = mean(Response),mu.per = mean(Response.per))
r1.int.mu$Outcome <- ifelse(r1.int.mu$mu.raw > 0, "Positive", "Negative")


ggplot(data=r1.int, aes(x=Minutes, y=Response, shape=Outcome)) + theme_bw() +
  geom_point(colour="#999999", alpha=0.5, size=5) +
  geom_point(data=r1.int.mu, aes(x=Minutes, y=mu.raw), shape=5, size=2.5) +
  geom_hline(yintercept=0, colour="#000000") +
  facet_wrap(~Labels, nrow=2) +
  scale_shape_manual(values=c(45,43)) +
  scale_x_continuous(limits=c(0,80), breaks=c(0,15,25,35,45,60,75)) +
  labs(y="Cortisol concentration difference in nmol/L (control - treated)")
```



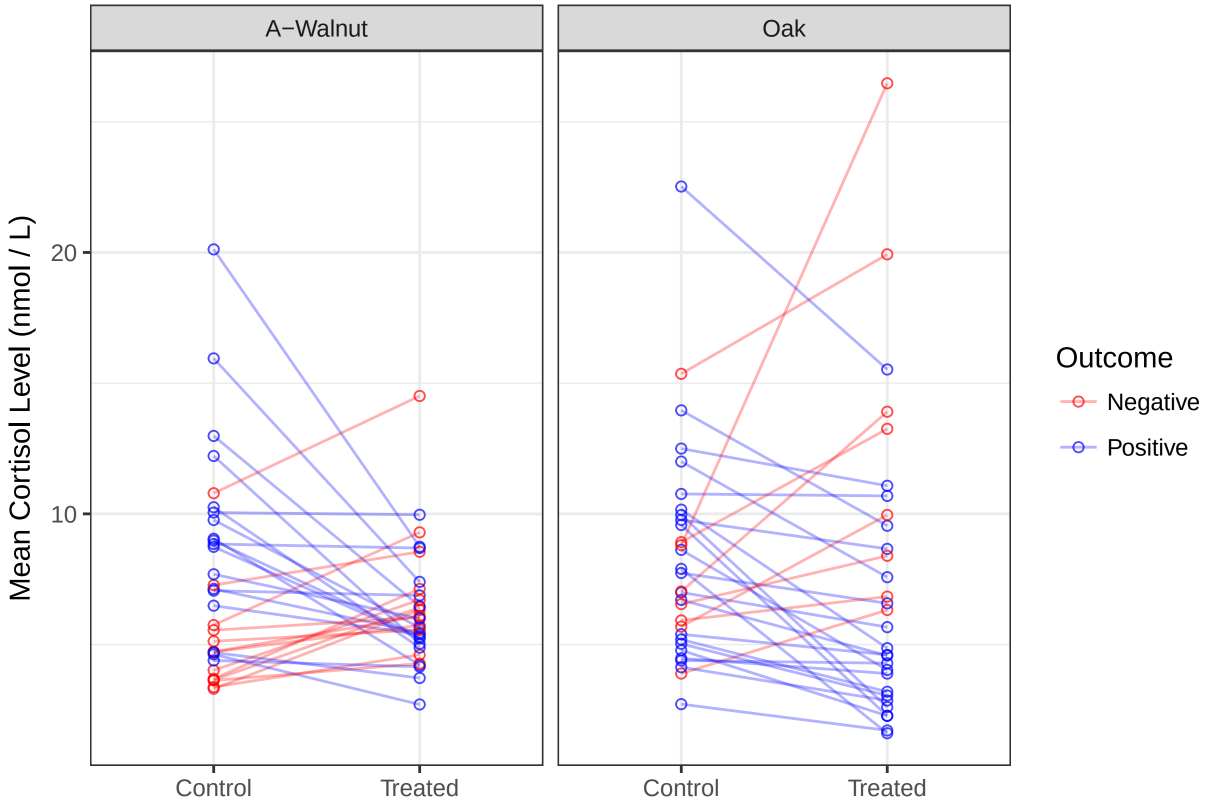

```
#percent basis? Its difficult to interpret but offers another perspective
ggplot(data=r1.int, aes(x=Minutes, y=Response.per, group=Anon)) + theme_bw() +
  geom_line(colour="#BBBBBB", linetype=3) +
  geom_point(data=r1.int.mu, aes(x=Minutes, y=mu.per, group=1)) +
  geom_hline(yintercept=0, colour="#333333", size=0.2) +
  facet_wrap(~Labels, nrow=2) +
  scale_x_continuous(limits=c(0,80), breaks=c(0,15,25,35,45,60,75)) +
  scale_y_continuous(labels=percent_format())
```



Hypothesis 1, mean overall stress response

This is parametersied as the mean cortisol level in the control room minus the mean cortisol level in the treated room.

```
#overall mean per subject

####
# Check mean of interval-interval differences (should be the same)
####

r1.mu <- r1 %>% group_by(Subject, Anon, TestType, Room) %>%
  summarise(Test.mu=mean(Cortisol.fitted.nmol, na.rm=TRUE))

r1.mu <- r1.mu %>% group_by(Subject, Anon) %>% mutate(testDif=Test.mu - lag(Test.mu))
r1.mu$Outcome <- ifelse(is.na(r1.mu$testDif), "X",
                 ifelse(r1.mu$testDif < 0, "Positive",
                  "Negative"))
r1.mu$Outcome <- ifelse(r1.mu$Outcome == "X", lead(r1.mu$Outcome), r1.mu$Outcome)

r1.mu$Label <- ifelse(r1.mu$Room == "A-Walnut", "Walnut", "Oak")

ggplot(data=r1.mu, aes(x=TestType, y=Test.mu, colour=Outcome, group=Subject)) +
  theme_bw() +
  geom_line(alpha=.3) +
  geom_point(alpha=.7, shape=1) +
  facet_wrap(~Room) +
  scale_colour_manual(values=c("#FF0000", "#0000FF")) +
  labs(x="", y="Mean Cortisol Level (nmol / L)")
```




```r
#create seperate data frames for each room
r1.mu.oak <- r1.mu %>% filter(Room == "Oak") %>%
  select(Subject, Anon, Room, TestType, Test.mu) %>%
  ungroup() %>% spread(TestType, Test.mu)

r1.mu.wal <- r1.mu %>% filter(Room == "A-Walnut") %>%
  select(Subject, Anon, Room, TestType, Test.mu) %>%
  ungroup() %>% spread(TestType, Test.mu)

#hist(r1.mu.wal$Control)
#hist(r1.mu.wal$Treated)
#hist(r1.mu.oak$Control)
#hist(r1.mu.oak$Treated)

#the data aren't normal enough, even with a log transform
#We use Wilcoxon rank sum, we're within-subjects so it's a paired test
#and with our parameterisation our alternative in this case is greater.
wilcox.test(r1.mu.oak$Control, r1.mu.oak$Treated, paired=TRUE,
            alternative="two.sided", conf.int=TRUE, conf.level=.95)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.mu.oak$Control and r1.mu.oak$Treated
## V = 317, p-value = 0.08407
## alternative hypothesis: true location shift is not equal to 0
## 95 percent confidence interval:
##  -0.2944102  2.7140185
## sample estimates:
## (pseudo)median
##       1.214015
```

```
wilcox.test(r1.mu.wal$Control, r1.mu.wal$Treated, paired=TRUE,
            alternative="two.sided", conf.int=TRUE, conf.level=.95)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.mu.wal$Control and r1.mu.wal$Treated
## V = 313, p-value = 0.2094
## alternative hypothesis: true location shift is not equal to 0
## 95 percent confidence interval:
##  -0.5255991  2.4924540
## sample estimates:
## (pseudo)median
##      0.8515471
```

```
#Summary info
r1.mu %>% filter(!is.na(testDif)) %>% group_by(Room, Outcome) %>%
  mutate(realtd=testDif*-1) %>% summarise(mu=mean(realtd), sd=sd(realtd),
                                          min=min(realtd), max=max(realtd), n=n())
```

Room	Outcome	mu	sd	min	max	n
A-Walnut	Negative	-1.973309	1.243451	-3.7216721	-0.4335732	13
A-Walnut	Positive	3.508476	3.269236	0.0844159	11.3775487	18
Oak	Negative	-5.364910	5.309842	-17.6692130	-0.9121788	8
Oak	Positive	2.914948	2.448286	0.0747172	7.3513351	22

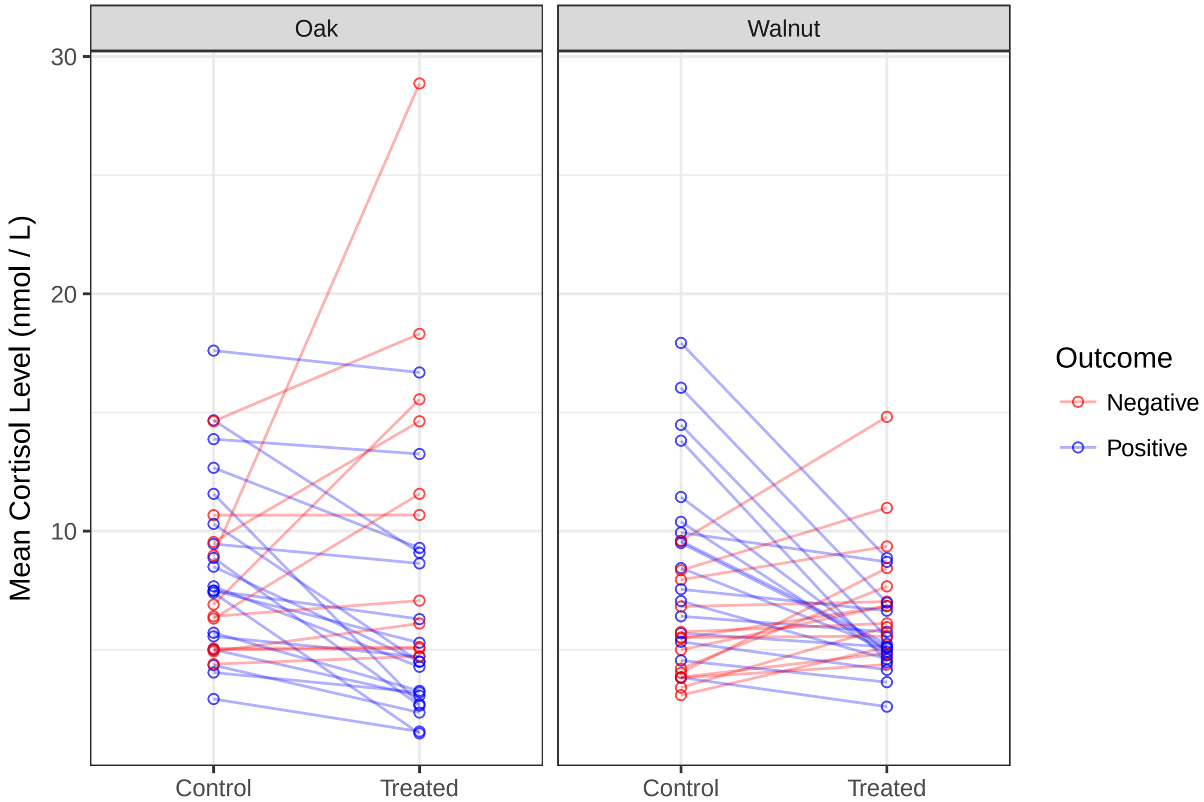
```
r1.mu.per <- bind_rows(r1.mu.oak, r1.mu.wal)
r1.mu.per$Response <- r1.mu.per$Control - r1.mu.per$Treated
r1.mu.per$Response.per <- (r1.mu.per$Control - r1.mu.per$Treated) / r1.mu.per$Control
r1.mu.per$Outcome <- ifelse(r1.mu.per$Response > 0, "Positive", "Negative")
r1.mu.per %>% group_by(Room) %>% summarise(mu=mean(Response.per),
                                           sd=sd(Response.per), min=min(Response.per),
                                           max=max(Response.per), n=n())
```

Room	mu	sd	min	max	n
A-Walnut	0.0065084	0.4541373	-0.9305624	0.5883899	31
Oak	0.0645386	0.5850293	-2.0069712	0.7964564	30

Hypotheses 1, response period stress level

```
#mean per subject for periods intervals 4,5,6,7

r1.re <- r1 %>% group_by(Subject, TestType, Room) %>% filter(Interval %in% c(4,5,6,7)) %>%
  summarise(Test.mu=mean(Cortisol.fitted.nmol, na.rm=TRUE))

r1.re <- r1.re %>% group_by(Subject) %>% mutate(testDif=Test.mu - lag(Test.mu))
r1.re$Outcome <- ifelse(is.na(r1.re$testDif), "X",
                 ifelse(r1.re$testDif < 0, "Positive",
                  "Negative"))
r1.re$Outcome <- ifelse(r1.re$Outcome == "X", lead(r1.re$Outcome), r1.re$Outcome)
r1.re$Label <- ifelse(r1.re$Room == "A-Walnut", "Walnut", "Oak")
ggplot(data=r1.re, aes(x=TestType, y=Test.mu, colour=Outcome, group=Subject)) +
  theme_bw() +
  geom_line(alpha=.3) +
```

```
  geom_point(alpha=.7, shape=1) +
  facet_wrap(~Label) +
  scale_colour_manual(values=c("#FF0000", "#0000FF")) +
  labs(x="", y="Mean Cortisol Level (nmol / L)")
```




```
#create seperate data frames for each room
r1.re.oak <- r1.re %>% filter(Room == "Oak") %>%
  select(Subject, Room, TestType, Test.mu) %>%
  ungroup() %>% spread(TestType, Test.mu)

r1.re.wal <- r1.re %>% filter(Room == "A-Walnut") %>%
  select(Subject, Room, TestType, Test.mu) %>%
  ungroup() %>% spread(TestType, Test.mu)

#hist(r1.re.wal$Control)
#hist(r1.re.wal$Treated)
#hist(r1.re.oak$Control)
#hist(r1.re.oak$Treated)
#the data aren't normal enough, even with a log transform
#We use Wilcoxon rank sum, we're within-subjects so it's a paired test
#and with our parameterisation our alternative in this case is greater.
wilcox.test(r1.re.oak$Control, r1.re.oak$Treated, paired=TRUE,
            alternative="greater", conf.int=TRUE, conf.level=.95)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.re.oak$Control and r1.re.oak$Treated
## V = 315, p-value = 0.04597
## alternative hypothesis: true location shift is greater than 0
## 95 percent confidence interval:
##  0.07924918        Inf
## sample estimates:
```

```
## (pseudo)median
##       1.019374
```

```
wilcox.test(r1.re.wal$Control, r1.re.wal$Treated, paired=TRUE,
            alternative="greater", conf.int=TRUE, conf.level=.95)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.re.wal$Control and r1.re.wal$Treated
## V = 312, p-value = 0.1083
## alternative hypothesis: true location shift is greater than 0
## 95 percent confidence interval:
##  -0.2290054        Inf
## sample estimates:
## (pseudo)median
##      0.9411696
```

```
r1.re %>% filter(!is.na(testDif)) %>% group_by(Room, Outcome) %>%
  mutate(realtd=testDif*-1) %>%
  summarise(mu=mean(realtd), sd=sd(realtd), min=min(realtd), max=max(realtd), n=n())
```

Room	Outcome	mu	sd	min	max	n
A-Walnut	Negative	-1.937551	1.580826	-5.2227070	-0.0588927	14
A-Walnut	Positive	4.105112	3.364521	0.5815726	9.3348801	17
Oak	Negative	-4.076906	5.971756	-19.8913806	-0.0079062	11
Oak	Positive	3.073132	2.380199	0.6264034	8.8591524	19

```
r1.re.per <- bind_rows(r1.re.oak, r1.re.wal)
r1.re.per$Response <- r1.re.per$Control - r1.re.per$Treated
r1.re.per$Response.per <- (r1.re.per$Control - r1.re.per$Treated) / r1.re.per$Control
r1.re.per$Outcome <- ifelse(r1.re.per$Response > 0, "Positive", "Negative")
r1.re.per %>% filter(abs(Response.per) > 1) %>% group_by(Room, Outcome) %>%
  summarise(mu=mean(Response.per), sd=sd(Response.per),
            min=min(Response.per), max=max(Response.per), n=n())
```

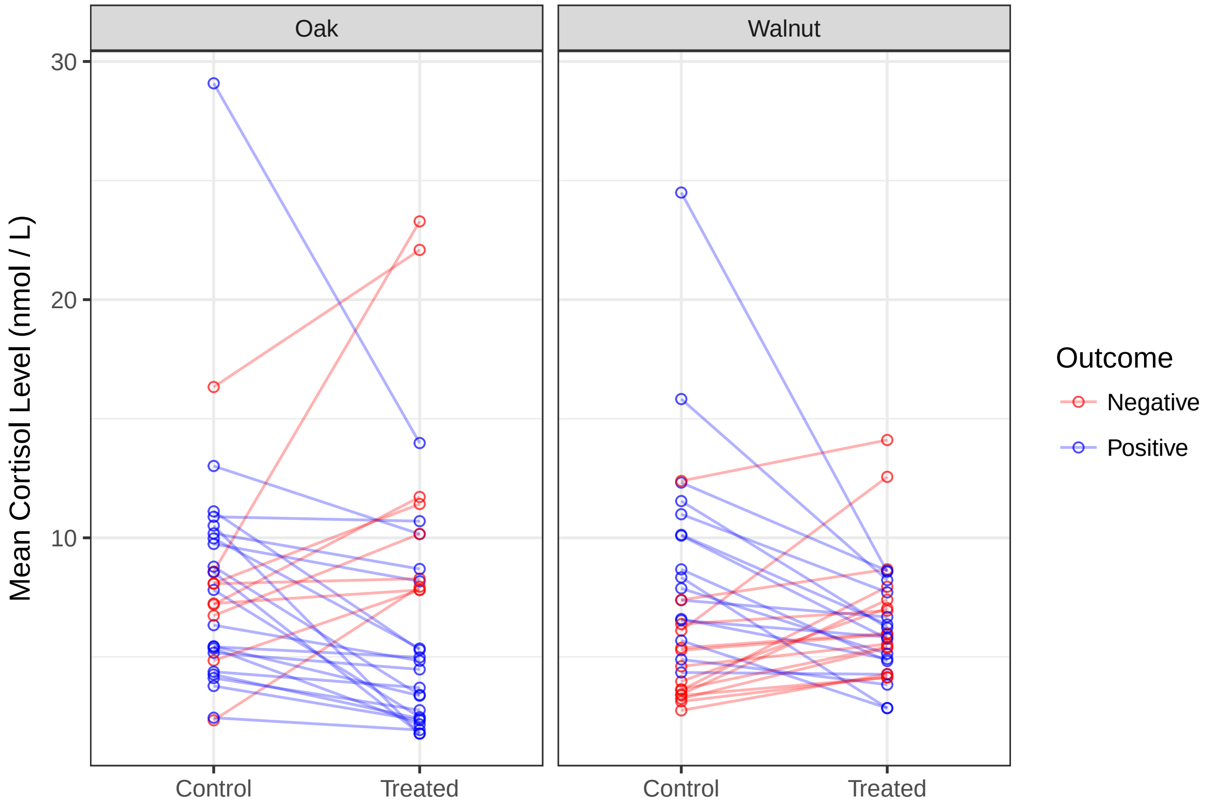
Room	Outcome	mu	sd	min	max	n
A-Walnut	Negative	-1.094919	NA	-1.094919	-1.094919	1
Oak	Negative	-1.735019	0.6818961	-2.217192	-1.252845	2

Check for differences within-subjects in initial 3 samples

If these are different this is problematic.

```
#mean per subject for periods intervals 123

r1.re <- r1 %>% group_by(Subject, TestType, Room) %>% filter(Interval %in% c(1,2,3)) %>%
  summarise(Test.mu=mean(Cortisol.fitted.nmol, na.rm=TRUE))

r1.re <- r1.re %>% group_by(Subject) %>% mutate(testDif=Test.mu - lag(Test.mu))
r1.re$Outcome <- ifelse(is.na(r1.re$testDif), "X",
                 ifelse(r1.re$testDif < 0, "Positive",
                  "Negative"))
r1.re$Outcome <- ifelse(r1.re$Outcome == "X", lead(r1.re$Outcome), r1.re$Outcome)
r1.re$Label <- ifelse(r1.re$Room == "A-Walnut", "Walnut", "Oak")
ggplot(data=r1.re, aes(x=TestType, y=Test.mu, colour=Outcome, group=Subject)) +
```

```
  theme_bw() +
  geom_line(alpha=.3) +
  geom_point(alpha=.7, shape=1) +
  facet_wrap(~Label) +
  scale_colour_manual(values=c("#FF0000", "#0000FF")) +
  labs(x="", y="Mean Cortisol Level (nmol / L)")
```




```
#create seperate data frames for each room
r1.re.oak <- r1.re %>% filter(Room == "Oak") %>%
  select(Subject, Room, TestType, Test.mu) %>%
  ungroup() %>% spread(TestType, Test.mu)

r1.re.wal <- r1.re %>% filter(Room == "A-Walnut") %>%
  select(Subject, Room, TestType, Test.mu) %>%
  ungroup() %>% spread(TestType, Test.mu)

#hist(r1.re.wal$Control)
#hist(r1.re.wal$Treated)
#hist(r1.re.oak$Control)
#hist(r1.re.oak$Treated)
#the data aren't normal enough, even with a log transform
#We use Wilcoxon rank sum, we're within-subjects so it's a paired test
#and with our parameterisation our alternative two-sided since this is a post-hoc test.
wilcox.test(r1.re.oak$Control, r1.re.oak$Treated, paired=TRUE,
            alternative="two.sided", conf.int=TRUE, conf.level=.95)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.re.oak$Control and r1.re.oak$Treated
## V = 307, p-value = 0.1294
## alternative hypothesis: true location shift is not equal to 0
## 95 percent confidence interval:
```

```
##  -0.6277666  2.7628969
## sample estimates:
## (pseudo)median
##       1.095396
```

```
wilcox.test(r1.re.wal$Control, r1.re.wal$Treated, paired=TRUE,
            alternative="two.sided", conf.int=TRUE, conf.level=.95)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.re.wal$Control and r1.re.wal$Treated
## V = 297, p-value = 0.3468
## alternative hypothesis: true location shift is not equal to 0
## 95 percent confidence interval:
##  -0.6839427  2.0169411
## sample estimates:
## (pseudo)median
##       0.766541
```

```
wilcox.test(r1.re.oak$Control, r1.re.oak$Treated, paired=TRUE,
            alternative="greater", conf.int=TRUE, conf.level=.95)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.re.oak$Control and r1.re.oak$Treated
## V = 307, p-value = 0.06468
## alternative hypothesis: true location shift is greater than 0
## 95 percent confidence interval:
##  -0.1229865        Inf
## sample estimates:
## (pseudo)median
##       1.095396
```

```
r1.re %>% filter(!is.na(testDif)) %>% group_by(Room, Outcome) %>%
  mutate(realtd=testDif*-1) %>% summarise(mu=mean(realtd), sd=sd(realtd),
                                          min=min(realtd), max=max(realtd), n=n())
```

Room	Outcome	mu	sd	min	max	n
A-Walnut	Negative	-2.055427	1.703267	-6.4538212	-0.5646980	15
A-Walnut	Positive	3.940227	3.775952	0.0765959	15.9198309	16
Oak	Negative	-4.565684	4.266447	-14.7063230	-0.2139715	9
Oak	Positive	3.409692	3.585542	0.1848818	15.1039944	21

```
r1.re.per <- bind_rows(r1.re.oak, r1.re.wal)
r1.re.per$Response <- r1.re.per$Control - r1.re.per$Treated
r1.re.per$Response.per <- (r1.re.per$Control - r1.re.per$Treated) / r1.re.per$Control
r1.re.per$Outcome <- ifelse(r1.re.per$Response > 0, "Positive", "Negative")
r1.re.per %>% filter(abs(Response.per) > 1) %>% group_by(Room, Outcome) %>%
  summarise(mu=mean(Response.per), sd=sd(Response.per), min=min(Response.per),
            max=max(Response.per), n=n())
```

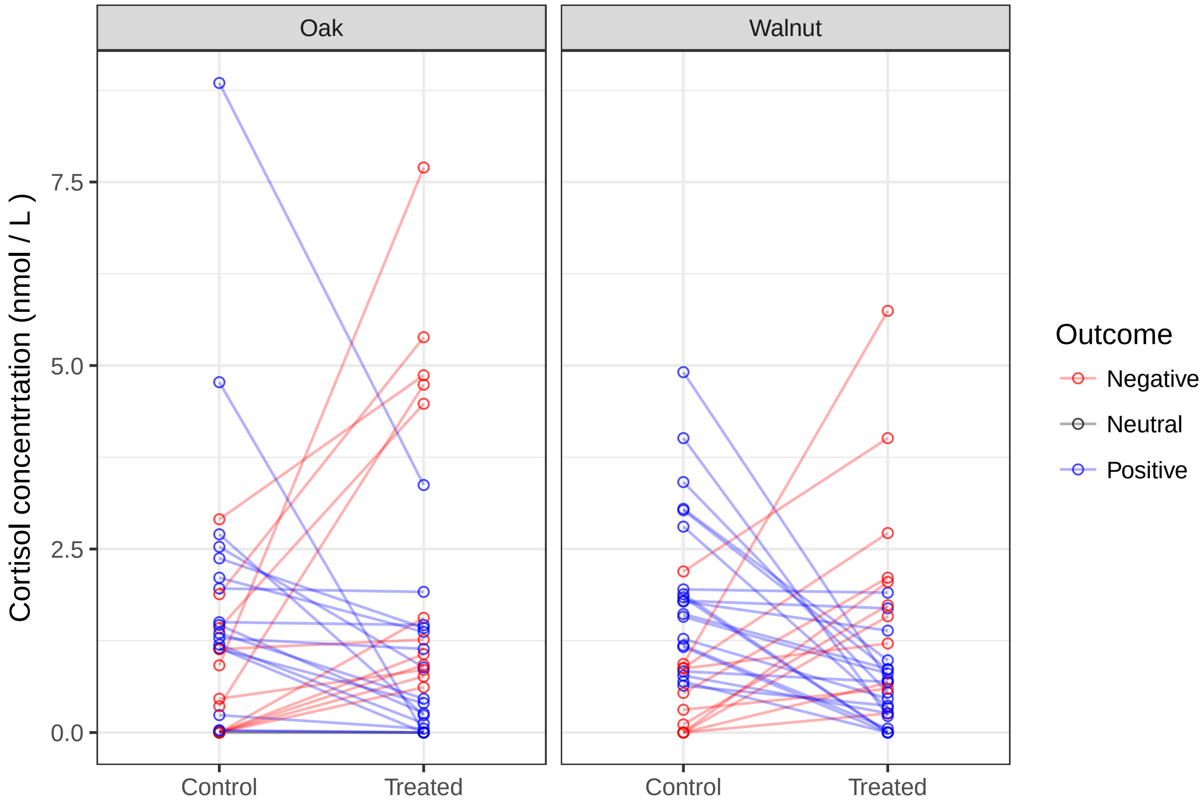
Room	Outcome	mu	sd	min	max	n
A-Walnut	Negative	-1.140045	0.0754844	-1.204365	-1.056943	3
Oak	Negative	-2.054472	0.4816285	-2.395035	-1.713909	2

Hypothesis 2

This is tricky. we find the minimum of either stage 4 or 5, then the maximum after 4 (could be the same as the minimum indicating no stress response detected).

```
r1.min <-  r1 %>% group_by(Subject,TestType, Room) %>% filter(Interval %in% c(4,5)) %>%
  filter(Cortisol.fitted.nmol == min(Cortisol.fitted.nmol)) %>% arrange(Subject) %>%
  mutate(Value="Min")
r1.max <- r1 %>% group_by(Subject,TestType, Room) %>% filter(Interval > 4) %>%
  filter(Cortisol.fitted.nmol == max(Cortisol.fitted.nmol)) %>% arrange(Subject) %>%
  mutate(Value="Max")

r1.min.oak <- r1.min %>% filter(Room == "Oak") %>%
  select(Subject, TestType, Room, Cortisol.fitted.nmol)
names(r1.min.oak)[4] <- "Min.cortisol.nmol"

r1.max.oak <- r1.max %>% filter(Room == "Oak") %>%
  select(Subject, TestType, Room, Cortisol.fitted.nmol)

r1.mm.oak <- r1.min.oak
r1.mm.oak$Max.cortisol.nmol <- r1.max.oak$Cortisol.fitted.nmol
#r1.mm.oak$Interval.max <- r1.max.oak$Interval

r1.mm.oak$Response <- r1.mm.oak$Max.cortisol.nmol - r1.mm.oak$Min.cortisol.nmol
r1.mm.oak$Response.per <- (r1.mm.oak$Max.cortisol.nmol - r1.mm.oak$Min.cortisol.nmol) /
  r1.mm.oak$Max.cortisol.nmol

r1.mm.oak.tst <- r1.mm.oak %>% ungroup() %>% select(Subject, TestType, Response, Room) %>%
  spread(TestType, Response)

r1.min.wal <- r1.min %>% filter(Room == "A-Walnut") %>%
  select(Subject, TestType, Room, Cortisol.fitted.nmol)
names(r1.min.wal)[4] <- "Min.cortisol.nmol"


r1.max.wal <- r1.max %>% filter(Room == "A-Walnut") %>%
  select(Subject, TestType, Room, Cortisol.fitted.nmol)

r1.mm.wal <- r1.min.wal
r1.mm.wal$Max.cortisol.nmol <- r1.max.wal$Cortisol.fitted.nmol


r1.mm.wal$Response <- r1.mm.wal$Max.cortisol.nmol - r1.mm.wal$Min.cortisol.nmol
r1.mm.wal$Response.per <- (r1.mm.wal$Max.cortisol.nmol - r1.mm.wal$Min.cortisol.nmol) /
  r1.mm.wal$Max.cortisol.nmol

r1.mm.wal.tst <- r1.mm.wal %>% ungroup() %>% select(Subject, TestType, Response, Room) %>%
  spread(TestType, Response)

#visualisation
r1.mm <- bind_rows(r1.mm.oak.tst, r1.mm.wal.tst)
r1.mm$diff <- r1.mm$Control - r1.mm$Treated
r1.mm$Outcome <- ifelse(r1.mm$diff == 0, "Neutral",
                        ifelse(r1.mm$diff > 0, "Positive", "Negative"))
r1.mm <- r1.mm %>% gather("TestType", "Response", 3:4)
r1.mm$Labels <- ifelse(r1.mm$Room == "A-Walnut", "Walnut", "Oak")
```

```
ggplot(data=r1.mm, aes(x=TestType, y=Response, colour=Outcome, group=Subject)) +
  theme_bw() +
  geom_line(alpha=.3) +
  geom_point(alpha=.7, shape=1) +
  facet_wrap(~Labels) +
  scale_y_continuous() +
  scale_colour_manual(values=c("#FF0000", "#000000", "#0000FF")) +
  labs(x="", y="Cortisol concentrtation (nmol / L )")
```




```
#the data aren't normal enough, even with a log transform
#We use Wilcoxon rank sum, we're within-subjects so it's a paired test
#and with our parameterisation our alternative in this case is greater.
#remove LFC73 from oak
r1.mm.oak.tst <- r1.mm.oak.tst %>% filter(!Subject == "LFV73")
wilcox.test(r1.mm.oak.tst$Control, r1.mm.oak.tst$Treated, paired=TRUE,
            alternative="greater", conf.int=TRUE, conf.level=.95)
```

```
## Warning in wilcox.test.default(r1.mm.oak.tst$Control, r1.mm.oak.tst
## $Treated, : cannot compute exact p-value with zeroes

## Warning in wilcox.test.default(r1.mm.oak.tst$Control, r1.mm.oak.tst
## $Treated, : cannot compute exact confidence interval with zeroes

##
##  Wilcoxon signed rank test with continuity correction
##
## data:  r1.mm.oak.tst$Control and r1.mm.oak.tst$Treated
## V = 225, p-value = 0.4398
## alternative hypothesis: true location shift is greater than 0
## 95 percent confidence interval:
##  -0.6160745        Inf
## sample estimates:
## (pseudo)median
##      0.0318109
```

```
wilcox.test(r1.mm.wal.tst$Control, r1.mm.wal.tst$Treated, paired=TRUE,
            alternative="greater", conf.int=TRUE, conf.level=.95)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.mm.wal.tst$Control and r1.mm.wal.tst$Treated
## V = 319, p-value = 0.08471
## alternative hypothesis: true location shift is greater than 0
## 95 percent confidence interval:
##  -0.141904       Inf
## sample estimates:
## (pseudo)median
##      0.3965971
```

```
r1.mm %>% filter(TestType == "Treated") %>% group_by(Room, Outcome) %>%
  summarise(mu=mean(diff), sd=sd(diff), min=min(diff), max=max(diff), n=n())
```

Room	Outcome	mu	sd	min	max	n
A-Walnut	Negative	-1.532690	1.285090	-4.8093847	-0.2605154	11
A-Walnut	Positive	1.403661	1.217861	0.0454898	4.1891556	20
Oak	Negative	-2.094687	1.989386	-6.7819517	-0.1305325	12
Oak	Neutral	0.000000	NA	0.0000000	0.0000000	1
Oak	Positive	1.269032	1.599837	0.0211969	5.4774348	17

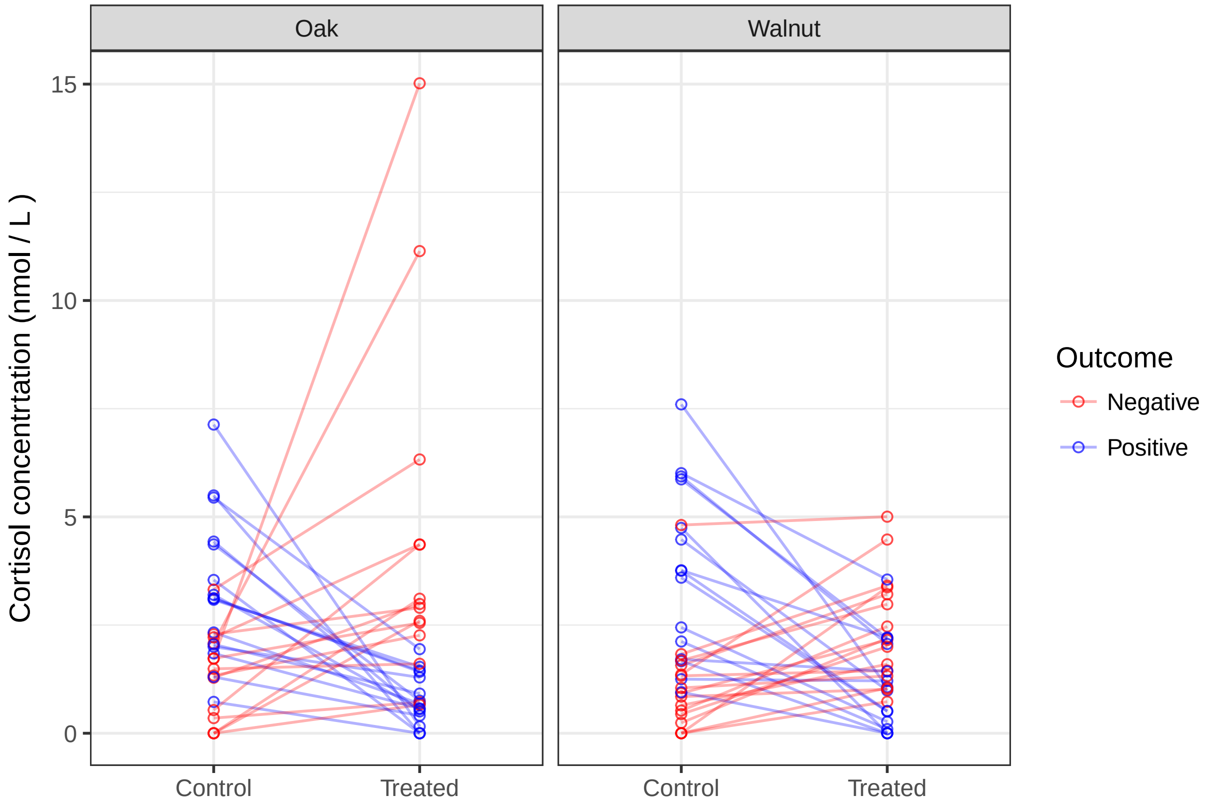
```
r1.mm.per <- bind_rows(r1.mm.oak.tst, r1.mm.wal.tst)
r1.mm.per$Response <- r1.mm.per$Control - r1.mm.per$Treated
r1.mm.per$Response.per <- (r1.mm.per$Control - r1.mm.per$Treated) /
  r1.mm.per$Control
r1.mm.per$Response.per <- ifelse(r1.mm.per$Response.per  == -Inf, -1,
                                 r1.mm.per$Response.per)
r1.mm.per$Outcome <- ifelse(r1.mm.per$Response > 0, "Positive", "Negative")

r1.mm.per %>% group_by(Room) %>% summarise(mu=mean(Response.per), sd=sd(Response.per),
                                           min=min(Response.per), max=max(Response.per),
                                           n=n())
```

Room	mu	sd	min	max	n
A-Walnut	-0.5799672	2.953863	-14.7188	1	31
Oak	NA	NA	NA	NA	30

Hypothesis 3

To parameterise recovery, we take the max value of intervals 4, 5, 6, and 7, and the final value (interval 7). If those two are equal (i.e., the max value is at interval 7), that means recovery didn't take place in the test period.

```
r1.rec <- r1 %>% group_by(Subject,TestType, Room) %>% filter(Interval > 3) %>%
  filter(Cortisol.fitted.nmol == max(Cortisol.fitted.nmol)) %>%
  arrange(Subject, TestType)

r1.rec7 <- r1 %>% group_by(Subject,TestType, Room) %>% filter(Interval == 7) %>%
  arrange(Subject, TestType)

r1.rec <- r1.rec %>% select(Subject, Interval, TestType, Room, Cortisol.fitted.nmol)
r1.rec$Final <- r1.rec7$Cortisol.fitted.nmol
names(r1.rec)[5] <- "Max"

r1.rec$RawDiff <- r1.rec$Max - r1.rec$Final
r1.rec$PerDiff <- (r1.rec$Max - r1.rec$Final) / r1.rec$Max

r1.rec.per.o <- r1.rec %>% filter(Room == "Oak") %>%
  select(Subject, TestType, PerDiff, Room) %>%
  spread(TestType, PerDiff)
r1.rec.per.w <- r1.rec %>% filter(Room == "A-Walnut") %>%
  select(Subject, TestType, PerDiff, Room) %>%
  spread(TestType, PerDiff)

r1.rec.raw.o <- r1.rec %>% filter(Room == "Oak") %>%
  select(Subject, TestType, RawDiff, Room) %>%
  spread(TestType, RawDiff)
r1.rec.raw.w <- r1.rec %>% filter(Room == "A-Walnut") %>%
  select(Subject, TestType, RawDiff, Room) %>%
  spread(TestType, RawDiff)

#visualisation
r1.recv <- bind_rows(r1.rec.raw.o, r1.rec.raw.w)
r1.recv$diff <- r1.recv$Control - r1.recv$Treated
r1.recv$Outcome <- ifelse(r1.recv$diff == 0, "Neutral",
                          ifelse(r1.recv$diff > 0, "Positive", "Negative"))
r1.recv <- r1.recv %>% gather("TestType", "Response", 3:4)
r1.recv$Labels <- ifelse(r1.recv$Room == "A-Walnut", "Walnut", "Oak")

ggplot(data=r1.recv, aes(x=TestType, y=Response, colour=Outcome, group=Subject)) +
  theme_bw() +
  geom_line(alpha=.3) +
  geom_point(alpha=.7, shape=1) +
  facet_wrap(~Labels) +
  scale_y_continuous() +
  scale_colour_manual(values=c("#FF0000", "#0000FF")) +
  labs(x="", y="Cortisol concentrtation (nmol / L )")
```




```r
#parameterisation changes here:
#we're looking at recovery, and our hypothesis is that one recovers less
#in the control room
wilcox.test(r1.rec.raw.o$Treated, r1.rec.raw.o$Control, paired=TRUE,
            alternative="greater", conf.int = TRUE, conf.level = .95, correct=FALSE)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.rec.raw.o$Treated and r1.rec.raw.o$Control
## V = 202, p-value = 0.7354
## alternative hypothesis: true location shift is greater than 0
## 95 percent confidence interval:
##  -1.341081       Inf
## sample estimates:
## (pseudo)median
##      -0.357873
```

```r
wilcox.test(r1.rec.raw.w$Treated, r1.rec.raw.w$Control, paired=TRUE,
            alternative="greater", conf.int = TRUE, conf.level = .95, correct=FALSE)
```

```
##
##  Wilcoxon signed rank test
##
## data:  r1.rec.raw.w$Treated and r1.rec.raw.w$Control
## V = 194, p-value = 0.855
## alternative hypothesis: true location shift is greater than 0
## 95 percent confidence interval:
##  -1.270479       Inf
## sample estimates:
## (pseudo)median
##     -0.5160458
```

```
r1.rec.per <- bind_rows(r1.rec.raw.w, r1.rec.raw.o)
r1.rec.per$Response <- r1.rec.per$Control - r1.rec.per$Treated
r1.rec.per$Response.per <- (r1.rec.per$Control - r1.rec.per$Treated) /
  r1.rec.per$Control
r1.rec.per$Response.per <- ifelse(r1.rec.per$Response.per == -Inf, -1,
                                  r1.rec.per$Response.per)
r1.rec.per$Outcome <- ifelse(r1.rec.per$Response > 0, "Positive", "Negative")

r1.rec.per$RP2 <- ifelse(r1.rec.per$Response.per < -1,
                         ((r1.rec.per$Control - r1.rec.per$Treated) /
                            r1.rec.per$Treated),
                         r1.rec.per$Response.per)
r1.rec.per %>% filter(abs(Response.per) == 1) %>% group_by(Room) %>% summarise(n=n())
```

Room	n
A-Walnut	6
Oak	6

```
r1.rec.per %>%  group_by(Room, Outcome) %>%
  summarise(mu=mean(Response), sd=sd(Response), min=min(Response),
            max=max(Response), n=n())
```

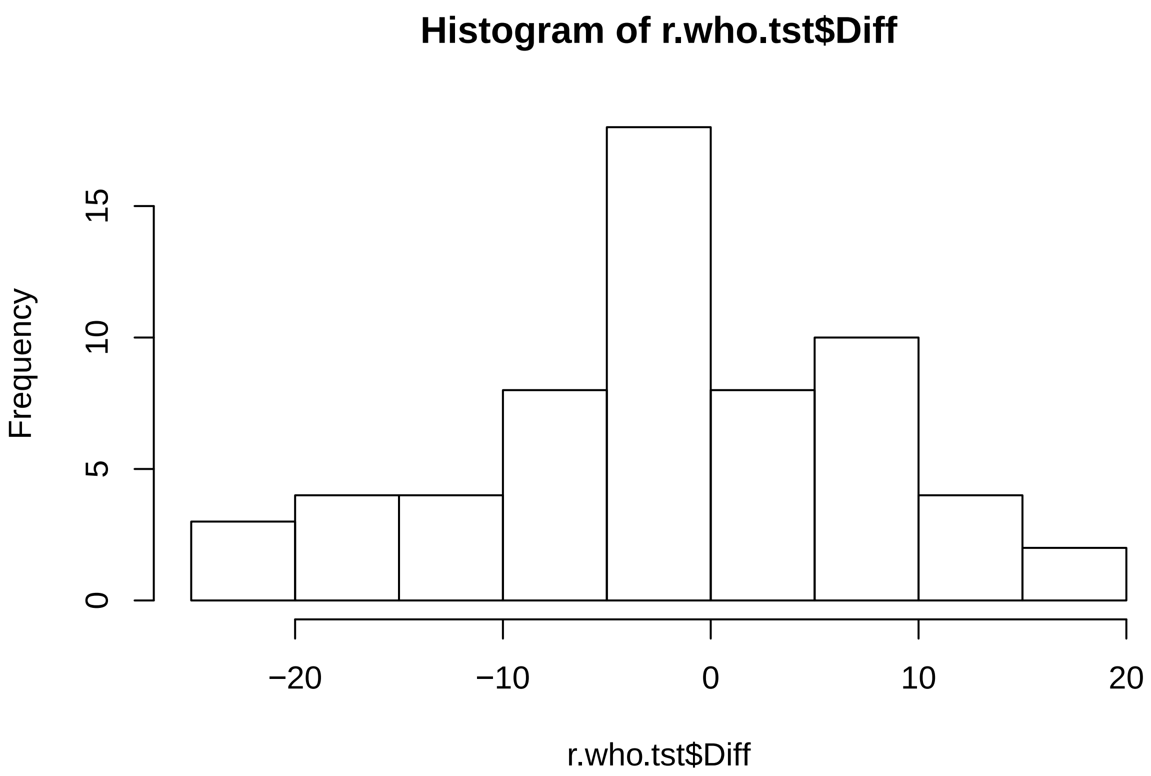
Room	Outcome	mu	sd	min	max	n
A-Walnut	Negative	-1.323781	0.9714643	-3.3732280	-0.1216024	16
A-Walnut	Positive	2.652560	1.7194774	0.0392063	6.5333193	15
Oak	Negative	-3.017331	3.7367412	-13.2944489	-0.1165732	14
Oak	Positive	2.561431	1.8187156	0.7083792	6.9775019	16

```
r1.rec.per %>% group_by(Room, Outcome) %>%
  summarise(mu=mean(Response.per), sd=sd(Response.per), min=min(Response.per),
            max=max(Response.per), n=n())
```

Room	Outcome	mu	sd	min	max	n
A-Walnut	Negative	-1.6713091	2.0395067	-8.1315217	-0.0400191	16
A-Walnut	Positive	0.7001692	0.3122006	0.0313931	1.0000000	15
Oak	Negative	-1.9979348	2.5099933	-7.7079414	-0.0783173	14
Oak	Positive	0.7333179	0.2050942	0.3545169	1.0000000	16

WHO-5 Well-being index

```
r.who.tst <- r1 %>% select(Subject, Test, TestType, Room, WHO5_Total) %>%
  group_by(Subject, TestType, Room) %>% summarise(WHO5_Total = mean(WHO5_Total*4)) %>%
  spread(TestType, WHO5_Total) %>% mutate(Diff = (Treated) - (Control))

r.who.tst$Outcome <- ifelse(r.who.tst$Diff == 0, "Neutral",
                 ifelse(r.who.tst$Diff > 0, "Positive", "Negative"))

hist(r.who.tst$Diff)
```




```
t.test(r.who.tst$Control, r.who.tst$Treated, paired=TRUE, conf.level = 0.95)
```

```
##
##  Paired t-test
##
## data:  r.who.tst$Control and r.who.tst$Treated
## t = 1, df = 60, p-value = 0.3213
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -1.246273  3.738076
## sample estimates:
## mean of the differences
##                1.245902
```

```
r.who <- r1 %>% select(Subject, Test, TestType, Room, WHO5_Total) %>%
  mutate(WHO5_100 = WHO5_Total *4)

r.who %>% group_by(Room, TestType) %>%
  summarise(min=min(WHO5_100), max=max(WHO5_100), med=median(WHO5_100),
            mean=mean(WHO5_100), sd=sd(WHO5_100))
```

Room	TestType	min	max	med	mean	sd
A-Walnut	Control	40	100	68	68.90323	12.41843
A-Walnut	Treated	32	100	68	65.67742	15.47002
Oak	Control	24	92	64	62.13333	18.10182
Oak	Treated	28	88	68	62.93333	16.00255

```
r.who.tst %>% group_by(Room) %>%
  summarise(min=min(Diff), max=max(Diff), med=median(Diff),
            mean=mean(Diff), sd=sd(Diff))
```

Room	min	max	med	mean	sd
A-Walnut	-24	12	0	-3.225807	10.193821

Room	min	max	med	mean	sd
Oak	-16	20	0	0.800000	8.938101

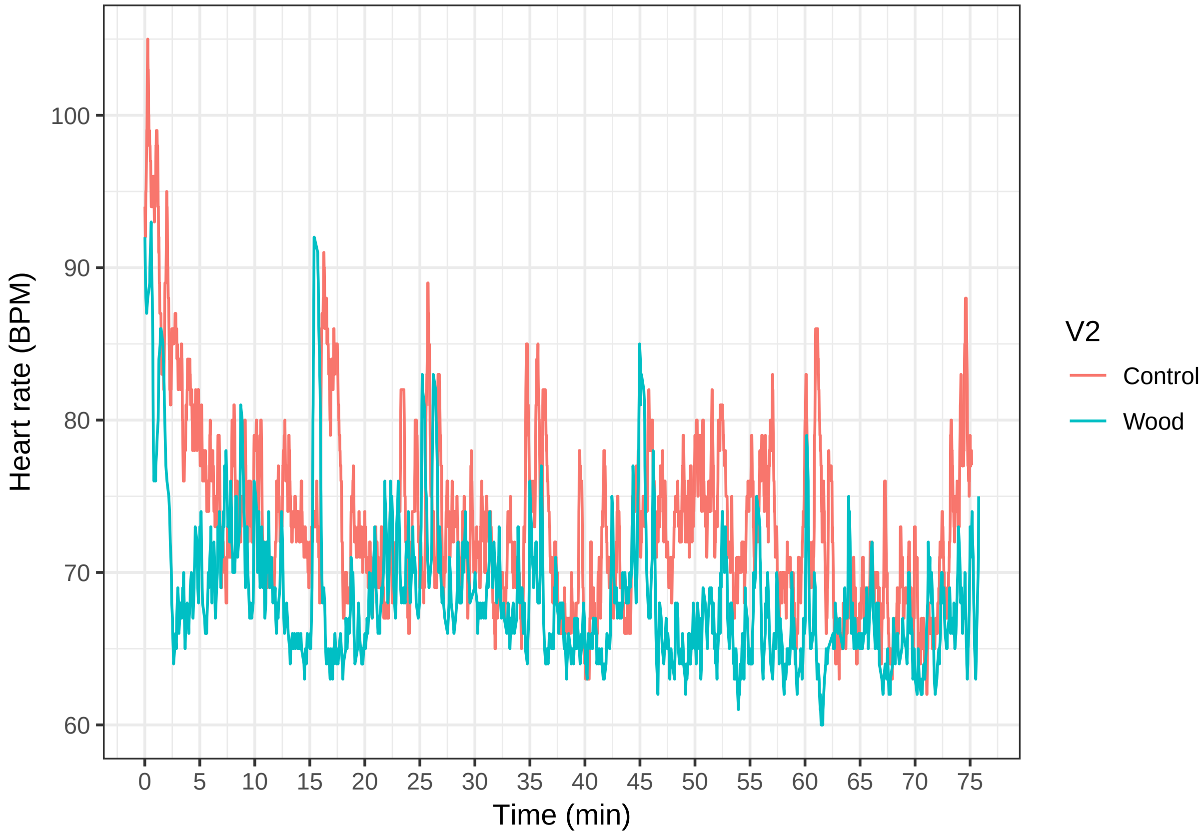
Heart rate

One example.

```
px.c <- read.csv("data/garminxml/garmindats_ANON-Control.txt", header = FALSE,
                 stringsAsFactors=FALSE)
px.w <- read.csv("data/garminxml/garmindats_ANON-Wood.txt", header = FALSE,
                 stringsAsFactors=FALSE)

px.c$datetime <- as.POSIXct(px.c$V4)
```

```
## Warning in strptime(xx, f <- "%Y-%m-%d %H:%M:%OS", tz = tz): unknown
## timezone 'zone/tz/2017c.1.0/zoneinfo/America/Los_Angeles'
```

```
px.w$datetime <- as.POSIXct(px.w$V4)
px.c <- px.c[complete.cases(px.c),]
px.w <- px.w[complete.cases(px.w),]
px.c <- px.c %>% select(V1, V2, V7, datetime) %>%
  mutate(timedif = as.numeric(difftime(datetime, lag(datetime, default=0))))
px.c[1,5] <- 1
px.c <- px.c %>% mutate(elapsed = cumsum(timedif), elapsed.min = cumsum(timedif/60))

px.w <- px.w %>% select(V1, V2, V7, datetime) %>%
  mutate(timedif = as.numeric(difftime(datetime, lag(datetime, default=0))))

px.w[1,5] <- 1
px.w <- px.w %>% mutate(elapsed = cumsum(timedif), elapsed.min = cumsum(timedif/60))

px <- bind_rows(px.c, px.w)
ggplot(data=px, aes(x=elapsed.min, y=V7, colour=V2)) + theme_bw() +
  geom_line() +
  scale_x_continuous(breaks=seq(0,75,5)) +
  labs(x="Time (min)",
       y=("Heart rate (BPM)"))
```



Environment

```
sessionInfo()
```

```
## R version 3.4.2 (2017-09-28)
## Platform: x86_64-apple-darwin15.6.0 (64-bit)
## Running under: macOS High Sierra 10.13.1
##
## Matrix products: default
## BLAS: /Library/Frameworks/R.framework/Versions/3.4/Resources/lib/libRblas.0.dylib
## LAPACK: /Library/Frameworks/R.framework/Versions/3.4/Resources/lib/libRlapack.dylib
##
## locale:
## [1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
##  [1] bindrcpp_0.2    zoo_1.8-0       scales_0.5.0    ggforce_0.1.1
##  [5] stringr_1.2.0   dplyr_0.7.4     purrr_0.2.3     readr_1.1.1
##  [9] tidyr_0.7.1     tibble_1.3.4    ggplot2_2.2.1   tidyverse_1.1.1
## [13] drc_3.0-1       MASS_7.3-47
##
## loaded via a namespace (and not attached):
##  [1] httr_1.3.1         jsonlite_1.5       splines_3.4.2
##  [4] modelr_0.1.1       gtools_3.5.0       assertthat_0.2.0
##  [7] highr_0.6          cellranger_1.1.0   yaml_2.1.14
## [10] backports_1.1.1    lattice_0.20-35    quantreg_5.33
```

```
## [13] glue_1.1.1         digest_0.6.12      rvest_0.3.2
## [16] minqa_1.2.4        colorspace_1.3-2   sandwich_2.4-0
## [19] htmltools_0.3.6    Matrix_1.2-11      plyr_1.8.4
## [22] psych_1.7.8        pkgconfig_2.0.1    broom_0.4.2
## [25] SparseM_1.77       haven_1.1.0        mvtnorm_1.0-6
## [28] tweenr_0.1.5       lme4_1.1-14        MatrixModels_0.4-1
## [31] mgcv_1.8-22        car_2.1-5          TH.data_1.0-8
## [34] nnet_7.3-12        lazyeval_0.2.0     pbkrtest_0.4-7
## [37] mnormt_1.5-5       survival_2.41-3    magrittr_1.5
## [40] readxl_1.0.0       evaluate_0.10.1    nlme_3.1-131
## [43] forcats_0.2.0      xml2_1.1.1         foreign_0.8-69
## [46] tools_3.4.2        hms_0.3            multcomp_1.4-7
## [49] munsell_0.4.3      plotrix_3.6-6      compiler_3.4.2
## [52] rlang_0.1.2        units_0.4-6        grid_3.4.2
## [55] nloptr_1.0.4       labeling_0.3       rmarkdown_1.6
## [58] gtable_0.2.0       codetools_0.2-15   reshape2_1.4.2
## [61] R6_2.2.2           lubridate_1.6.0    knitr_1.17
## [64] udunits2_0.13      bindr_0.1          rprojroot_1.2
## [67] stringi_1.1.5      parallel_3.4.2     Rcpp_0.12.13
## [70] tidyselect_0.2.0
```